A SEDIMENTOLOGIC -STRATIGRAPHIC INVESTIGATION OF MARSDENIAN (NAMURIAN R_2A-B) SEDIMENTS IN THE CENTRAL PENNINES

STEPHEN ANAGO OKOLO, M.S. KENTUCKY

1982

VOLUME 1: TEXT

ABSTRACT

The Marsdenian (R_{2a-b}) sediments constitute the third major clastic influx into the Central Pennine Basin, following the first and second influxes during the Skipton Moor Grit (E_{1c}) and Kinderscoutian (R_1) intervals respectively. The Marsdenian influx involves three distinct delta advances during the Scotland Flags (R_{2a}), Pule Hill (R_{2b}) and Hazel Greave (R_{2c}) intervals. Each of these Marsdenian fills represents a roughly similar type of deltaic advance into the basin, which subsequently undergoes abandonment and widespread transgression probably associated with eustatic sea level rise characterised by its distinct goniatite band.

In this sedimentological and stratigraphical investigation of these Marsdenian sediments in the Central Pennine Basin between Wharfedale and Longdendale, 20 lithofacies are recognized, described and interpreted in hydrodynamic terms on the basis of their internal evidence. Five Facies Associations are recognized in which lithofacies succeed one another with variable predictability.

The Deep Water Association, the lowest association recognised in only one locality in the southwest parts of the study area is some 122m thick, and involves interbeds of marine mudstone and turbidite-like sandstones of various thickness scales. The mudstones are considered to represent sourceward ponding of sediments, perhaps during sea level rise.

The Delta Slope Association, the lowest association in most other localities is a coarsening upward sequence with mudstones and siltstones dominating the lower parts, while medium-grained to occasional coarse-grained sandstones dominate the upper parts, which show great lateral variation. Non turbiditic density current deposits associated with

slumps, occur locally. Minor subaqueous extensions of the distributary channels are recognized within the Slope Association, particularly in the upper parts. The Association is interpreted as a prograding slope (Prodelta-Mouth bar) of a fluvially dominated deltaic coastline. The turbidites, termed Prodelta Turbidites, are products of dense sediment-laden discharge issuing from the distributary mouth bar areas during flood period and so entered the basin as hyperpycnal flows.

The Distributary Channel Association involves 2 distinct channel types, namely the Major Channels and the Sheet Channels. The Major Channels are lenticular in cross-section when they are fully exposed, while the Sheet Channels are characterised by extensive planar erosional bases which can be traced in outcrop for hundreds of metres. The Major Channels occur in Complexes of up to 4, with a common thickness range of 3-30m, and some of the thick ones may be made up of smaller sized channels termed scour based sand bodies. Several types of sandstone lithofacies whose vertical order is variable occur within the Major Channels. However there is a preferred upwards lithofacies sequence of Erosion surface → Massive Sandstone → Large Scale Cross Bedding → Trough Cross- or Tabular Cross-Bedded Sandstone → other smaller scale cross bedding. Most of the massive beds are thought to be trough deposits of large bedforms or products of scour troughs incised at the basal parts of a slip face of a large bedform. The Large Scale Cross Beds are regarded as the products of alternate bars developed in rivers of low sinuosity. Dunes and sandwaves occurring in shallower parts of the channel produced the cosets of tabular cross-bedding. Smaller bedforms superimposed on the larger bedforms during falling stage produced the erosional surfaces within the individual sets of the larger bedform. Side and/or vertical filling mechanisms operated during the infilling of the Major Channels. Most Sheet Channel fill thicknesses lie between 1 and 10m (commonly 2-4m) and these channels are interpreted as of low sinuosity.

The following genetic groupings of lithofacies are distinguishable in the Interdistributary Complex Association: Alternating Tabular Bedded Sandstone and Mudstone Units, interpreted as levee progradation units. Alternating lenticular sandstone bed and mudstone units, considered as crevasse splay sediments; channel unit cutting into sharp based tabular sandstone, regarded as crevasse channels truncating levee deposits; gradationally based sandstone units, thought to represent minor mouth bar sediments into an interdistributary bay.

The widespread coal on seatearth that characterises the abandonment lithofacies association is taken to indicate the overall colonization of the delta top by vegetation.

The lithofacies analysis is used as the basis for establishing and defining the three Marsdenian deltas mentioned above, based on the construction of the following new chrono- and lithostratigraphical subdivision of the Marsdenian sediments: Scotland Flags Time Stratigraphical Interval involving all the lithofacies occurring between the bases of the bands of *R. gracile* and *R. bilingue* typical. All the main sandstone dominated units occurring at the upper parts of the interval and which had hitherto been variously given multifarious rock-stratigraphical names are termed Scotland Flags. The mudstone dominated unit which usually occurs below the Scotland Flags are called Scotland Flags Mudstone. The same nomenclatural procedure applies to their overlying Pule Hill- and Hazel Greave Time Stratigraphical Intervals.

Plots of bands of goniatites in accordance with their stratigraphical levels suggests that band of _R. gracile_, _R. bilingue_ typical, _R. bilingue_ late and _R. superbilingue_ are reliable for stratigraphical correlation based on their widespread distribution,whereas bands of _R. bilingue_ early, and _R. metabilingue_ are not due to their restricted distribution.

Fourteen ichnogenera are recognized, described and used in palaeo-environmental reconstruction. Their vertical distributions do not appear to be bathymetrically controlled, excepting perhaps ichnogenus _Olivellites_. Rather the mode of deposition of their host sediment exerted a more significant control.

Palaeocurrent indicators suggest currents dominantly towards the southwest but also southeast. The long axes of _Pelecypodichnus_ and plants have a preferred orientation parallel to the current.

Among the many factors that controlled the sedimentation are the following: River processes, limited wave influence, relative basin level changes, subsidence and compaction, climate, salinity and predepositional topography.

On the whole, the Marsdenian sediments are interpreted as deposits of Fluvial-Dominated High Constructive Lobate Deltas.

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to many people who contributed greatly to this work, particularly Dr John D. Collinson who was an enthusiastic, encouraging and helpfully critical supervisor and who also was always available to review and discuss the lines of investigations adopted, yet allowing me a free hand in the choice and presentation of the material.

I am indebted to Professor Gilbert Kelling, Doctors T. Elliott, M. Leeder, B. Rust, P. McCabe, C. Jones, E. Kerey, D. Macdonald and Messrs. J.Ineson and J. Constable for their helpful discussions on the various aspects of the sedimentology. The ideas expressed in the trace fossil section owes a great deal to Drs. J. Pollard and M. Eager with whom I have had many stimulating discussions on several occasions. The stratigraphy section owes much to Dr W. Ramsbottom who kindly identified the various goniatite fossils collected from the field. Dr A.A. Wilson kindly secured the I.G.S. borehole logs used and also provided the working space.

Many thanks to Mr. M.W. Stead and his staff for providing technical facilities, particularly Mr. D. Kelsall and Miss P. Douglas for taking numerous photographs, and to Mrs. J. Cliff for typing this thesis. Of the several people of West Yorkshire whose friendship lightened up the field conditions, I particularly would like to thank Mr & Mrs H. Bailey of Hebden Bridge, Mrs R. Smith of Huddersfield and Dr & Mrs M. Gee of Ripponden whose exceptional hospitality did much to encourage me during some trying field conditions.

I am grateful to Drs. G. Anastasakis and E. Kerey and Messrs. D. Cronshaw, A. Huque, E. Okonkwo, S. Theodorikas, P. Gambles and M. Niamatullah, who through their friendship made my stay at Keele an enjoyable one.

My greatest debt is to Mr & Mrs F.O. Okolo, my parents, at Odenigbo Nsukka, Anambra State, Nigeria, who stood by me all through these 3½ years, and encouraged me in various ways.

This work was supported by the Government of Anambra State of Nigeria Scholarship from January 1979 to June 1980 and by the Federal Government of Nigeria Scholarship from September 1980 to date, which I acknowledge with many thanks. I am also very grateful to Texaco Overseas Nigeria Petroleum Company for granting me the educational leave to undertake this study.

CONTENTS

		Page No.
ABSTRACT		i.
ACKNOWLEDGEMENTS		v.
CONTENTS OF VOLUME 1		vii.
LIST OF TABLES		xv.
CHAPTER 1: INTRODUCTION		1
1.1.	Aims of research	1
1.2.	Thesis Layout	2
1.3.	The Study Area	3
1.4.	Structure of the area	4
1.5.	Previous Research	7
	Stratigraphy	7
	Sedimentology	18
1.6.	Methods of study	25
1.6.1.	Field Methods	25
1.6.2.	Laboratory Methods	26
CHAPTER 2: STRATIGRAPHY		28
2.1.	BIOSTRATIGRAPHY	28
2.1.1.	The Reticuloceras Gracile Bands	31
2.1.2.	The Reticuloceras Bilingue Bands	35
2.1.2.1.	Band of Reticuloceras Bilingue Early	37
2.1.2.2.	Band of Reticuloceras Bilingue Typical	37
2.1.2.3.	Band of Reticuloceras Bilingue late	40
2.1.3.	The Reticuloceras Superbilingue Band	44
2.2.	CHRONO- & LITHO-STRATIGRAPHY	49

2.2.1.	Terminology and Introduction	49
2.2.2.	The Scotland Flags Interval	50
2.2.2.1.	Scotland Flags Mudstone	53
2.2.2.2.	Scotland Flags	54
2.2.3.	Pule Hill Interval	59
2.2.3.1.	Pule Hill Mudstone	63
2.2.3.2.	Pule Hill Grit	63
2.2.4.	Hazel Greave Interval	73
2.2.4.1.	Hazel Greave Mudstone	78
2.2.4.2.	Hazel Greave Grit	78
2.2.5.	Inter area Relationships and Interpretation	83
CHAPTER 3:	LITHOFACIES	87
3.0.	Definition	87
3.1.	Lithofacies 1. Unfossiliferous Mudstone	88
3.1.1.	Description	88
3.1.2.	Interpretation	88
3.2.	Lithofacies 2. Fossiliferous Mudstone	90
3.2.1.	Description	90
3.2.2.	Interpretation	92
3.3.	Lithofacies 3. "Bluestone"	92
3.3.1.	Description	92
3.3.2.	Interpretation	93
3.4.	Lithofacies 4. Carbonaceous Mudstone	94
3.4.1.	Description	94
3.4.2.	Interpretation	94
3.5.	Lithofacies 5. Mudstones and Siltstones	95
3.5.1.	Description	95
3.5.2.	Interpretation	96

3.6.	Lithofacies 6. Siltstones	97
3.6.1.	Description	97
3.6.2.	Interpretation	98
3.6.3.	Deformational Structures in Siltstones	98
3.6.3.1.	Description	98
3.6.3.2.	Orientation of the folds	100
3.6.3.3.	Genesis of the structures	101
3.7.	Lithofacies 7. Rippled Silty Sandstone	104
3.7.1.	Description	104
3.7.2.	Interpretation	106
3.8.	Lithofacies 8. Trough Cross Laminated Sandstone	107
3.8.1.	Description	107
3.8.2.	Interpretation	108
3.9.	Lithofacies 9. Parallel Laminated Sandstone	109
3.9.1.	Description	109
3.9.2.	Interpretation	110
3.9.3.	Deformational Structures in Parallel Laminated Sand-stone	111
3.9.3.1.	Description	111
3.9.3.2.	Interpretation	112
3.10.	Lithofacies 10. Trough Cross Bedded Sandstone	112
3.10.1.	Description	112
3.10.2.	Interpretation	114
3.11.	Lithofacies 11. Tabular Cross Bedded Sandstone	116
3.11.1.	Description	116
3.11.2.	Interpretation	118
3.11.3.	Deformational Structures in Tabular Cross Bedded Sandstone	119
3.11.3.1.	Description	119
	Orientation of the folds	120

3.11.3.2.	Interpretation	121
3.12.	Lithofacies 12	123
3.12.1.	Description	123
3.12.2.	Interpretation	128
3.13.	Lithofacies 13. Scour Based Sand Bodies	129
3.13.1.	Description	129
3.13.2.	Interpretation	136
3.13.3.	Deformation Structures in Scour Based Sand Bodies	136
3.14.	Lithofacies 14. Horizontal Bedded Sandstone	136
3.14.1.	Description	136
3.14.2.	Interpretation	138
3.15.	Lithofacies 15. Lenticular Sandstone Beds	138
3.15.1.	Description	138
3.15.2.	Interpretation	139
3.16.	Parallel Sided Sandstone	139
3.16.1.	Description	139
3.16.2.	Interpretation	140
3.17.	Lithofacies 17. Massive Sandstone	141
3.17.1.	Description	141
3.17.2.	Interpretation	142
3.18.	Pinch and Swell Sandstone	143
3.18.1.	Description	143
3.18.2.	Interpretation	144
3.19.	Lithofacies 19. Turbidite-like Sandstone	144
3.19.1.	Description	144
3.19.2.	Interpretation	146
3.20.	Lithofacies 20. Seatearths and Coals	147
3.20.1.	Description	147
	Fireclay	147

	Ganister	148
	Seatearth proper	148
	Type A Coals	149
	Type B Coals	149
	Type C Coals	149
3.20.2.	Interpretation	150

CHAPTER 4: FACIES ASSOCIATION 151

4.0.	Introduction	151
4.1.	Deep Water Association	153
4.1.1.	Description	153
4.1.2.	Interpretation	154
4.2.	Delta Slope Association	155
4.2.1.	Limits of the Association	155
4.2.2.	Description and Interpretation	156
4.2.2.1.	Finer Lithofacies Sub-Association	156
	Description	157
	Interpretation	160
4.2.2.2.	Coarser Lithofacies Sub-Association	164
	Description	165
	Interpretation	170
Relationship within the Delta Slope Association		173
4.3.	Delta Top Assemblage	174
4.3.0.	Definition and Introduction	174
4.3.1.	Distributary Channel Association	175
4.3.1.1.	Major Channel Sub-Association	176
	Introduction	176
	Channel fills and complexes	176
	Dimensions of the Channels	178

	Erosion Surfaces of the Channels	180
	Channel Fill Sequences and Lithofacies Relationships	182
	Palaeocurrents and Mechanisms of Erosion, Channel Filling and Abandonment	185
	Genesis of the Massive Sandstone and Large Scale Cross Bedding	194
	Interpretations and Summary	199
	Deformational Structures and their Interpretations	201
	Orientation of the folds	202
	Genesis of the Structure	203
	Channel Bank failure Model	203
4.3.1.2.	Sheet Channel Sub-Association	204
	Introduction	204
	Description	204
	Interpretation	206
4.3.2.	Interdistributary Complex Associations	207
4.3.2.0.	Introduction	207
4.3.2.1.	Alternating Tabular Bedded Sandstone and Mudstone Units	208
4.3.2.2.	Alternating Lenticular Sandstone Beds and Mudstone Units	209
4.3.2.3.	Channel Units Cutting into Sharp based Sandstone/ Mudstone Units	210
4.3.2.4.	Gradationally based Sandstone Units and Channels	210
	Channels	210
	Interpretation	212
	Context	212
	Sequences	212
4.3.3.	Abandonment Lithofacies Association	216
4.3.3.0.	Introduction	216
4.3.3.1.	Description	217

4.3.3.2. Occurrence 217

4.3.3.3. Distribution 218

4.3.3.4. Interpretation 219

4.3.4. Relationships within the Delta Top Assemblage 220

4.4. Summary to Facies Association 222

CHAPTER 5. TRACE FOSSILS 223

5.0. Introduction and definition 223

5.1. Ichnogenus Arenicolites carbonarius 226

5.2. Ichnogenus Arthrophycus 229

5.3. Ichnogenus Cochlichnus 231

5.4. Ichnogenus Gyrophyllites 231

5.5. Ichnogenus Kouphichnium rossendalensis 233

5.6. Ichnogenus Palaeophycus 234

5.7. Ichnogenus Pelecypodichnus 236

5.8. Ichnogenus Phycodes cf. curvipalmatum 242

5.9. Ichnogenus ?Phycodes palmatum 245

5.10. Ichnogenus Planolites 246

5.11. Ichnogenus Olivellites 248

5.12. Ichnogenus 'Scolicia' 252

5.13. Ichnogenus Zoophycos 253

5.14. Loop and Sinuous Trails 255

5.15.1. Distribution of the Trace Fossils 256

5.15.2. Interpretation 257

CHAPTER 6. BASIN ANALYSIS AND SYNTHESIS 260

6.1. Palaeocurrents 260

6.1.1. Introduction and Method of Study 260

6.1.2. Treatment of the Palaeocurrent Data 262

6.1.3. Interpretation 265

6.2.	Major Factors Controlling Sedimentation	265
6.2.0.	Introduction	265
6.2.1.	River Processes Factors	266
6.2.2.	Coastal Processes Factors	269
6.2.3.	Structural behaviour	270
6.2.3.1.	Relative Sea level changes	271
6.2.3.2.	Subsidence and Compaction	273
6.2.3.3.	Predepositional Topography	274
6.2.4.	Climatic Factors	275
6.2.5.	Salinity	276
6.2.6.	Synthesis of the Factors Controlling Sedimentation	277
6.3.	Palaeogeography	278
6.3.1.	Introduction. Early Namurian Sedimentation	278
6.3.2.	Marsdenian Sedimentation	280
6.3.2.1.	Scotland Flags Interval	280
6.3.2.2.	Pule Hill Interval	282
6.3.2.3.	Hazel Greave Interval	285
6.4.	The Marsdenian Delta Type and Morphology	286

LIST OF TABLES

Table Number		Page
1.	Correlation Chart showing Nomenclature of Marsdenian lithofacies and adjacent Namurian Units.	29
2.	Correlation Chart showing Goniatite zones and subzones within the Marsdenian Stage.	30
3A.	Bands of *R. gracile* variants.	32
3B.	" " " " "	33
4.	Band " " *bilingue* Early.	36
5A.	" " " " Typical.	38
5B.	" " " " "	39
6A.	" " " " Late	41
6B.	" " " " "	42
7.	" " *R. metabilingue.*	45
8A.	" " *R. superbilingue.*	46
8B.	" " " "	47
9.	Thickness of Scotland Flags Interval.	51
10.	Thickness of Scotland Flags.	55
11.	Thickness of Pule Hill Interval.	60
12.	Thickness of Pule Hill Grit.	67
13.	Thickness of Hazel Greave Interval.	74
14.	Thickness of Hazel Greave Grit.	75
15.	Thickness of Marsdenian Stage (R_{2A-B}) of this study.	84
16.	Features of Scour Based Sand Bodies.	130 & 131
17.	Features of Lenticular Bedded Sandstone.	132
18.	Number of Channels in Channel Complexes.	177
19.	Features of the Distributary Channels.	182B
20.	The Dimensions of *Arenicolites* Carbonarius.	227

CHAPTER 1: INTRODUCTION

1.1. AIMS OF RESEARCH

The detailed comparative studies of the Namurian deltaic sequences in the Pennine region of England have been going on for some two decades, beginning with the work of Allen (1960). Following the latter, Walker (1966a & b) and Collinson (1966, 1967, 1968, 1969 and 1970a) studied the Namurian R1c succession of north Derbyshire and established a broadly coarsening upwards sequence of turbidites, delta slope and delta top sequences. McCabe (1975) extended the study of the same succession to the northern part of the basin. Baines (1977) investigated the Skipton Moor Grits (Namurian E1c), which is also in the northern parts of the basin.

In contrast, the Namurian R_{2a-b} (middle-lower Marsdenian) succession of the Central Pennine Basin has received little attention so far, from the point of view of sedimentology. Excepting the paper by Collinson, Jones and Wilson (1977) and those of Jones (1979, 1980), the only information on the sedimentology of rocks of equivalent age are restricted to the unpublished theses of Mayhew (1967) and Ashton (1974). Even then, Mayhew's (1967) work was in northwest Derbyshire while Ashton's (1974) was in North Staffordshire basin. Collinson *et al*'s (1977) work was in the area west of Blackburn while Jones' (1979, 1980) investigation was in North Staffordshire basin. The field report in the Central Pennines by Benfield (1969), and the investigation by Collinson and Banks (1975) in south east Lancashire, were on units younger than the Middle-Lower Marsdenian age. This disparity in research has created a gap in the knowledge of the fill of the Pennine Basin.

The present study is therefore intended to bridge this gap. It involves the rocks of Middle-Lower Marsdenian age (Namurian R_{2a-b}) in the Pennine region of Central and Northern England. The rocks deposited during the Marsdenian stage (Namurian R_2) are generally referred to as the Middle Grit Group (Wright et al. 1927; Stephen et al. 1953, Earp et al. 1961). This group commences with the Reticuloceras gracile marine bands and includes a number of other marine bands such as the bands of the three variants of Reticuloceras bilingue and those of Reticuloceras metabilingue and Reticuloceras superbilingue (Table 1). The top of the group is usually regarded as the base of Gastrioceras cancellatum marine band (Table 1). The four main sandstone formations in this group include the following (in ascending order): Scotland Flags (or its equivalent), the Pule Hill Grit (or its equivalents), the Hazel Greave Grit (or its equivalents) and the Huddersfield White Rock (Table 1). The Huddersfield White Rock has not been considered in this study. The Reticuloceras superbilingue marine band therefore marks the top of the Marsdenian sediments studied (Fig. 1A).

A detailed facies analysis of these Marsdenian sediments will be made with the aim of deciphering the processes that operated during their sedimentation. This will be followed by a reconstruction of their environments of deposition, based on comparison with recent models for palaeoenvironmental interpretation. The study was planned to be a full basin analysis type.

1.2. THESIS LAYOUT

The main text of the thesis, including some figures constitutes Volume 1. Most other figures on A4 paper and plates are bound together to form Volume 2. This separation is expected to provide some convenience to the reader as several figures and plates will be referred to several times. Large fold-out figures, maps and diagrams that cannot conveniently be reduced to A4 paper are in the pocket at the back of Volume 2.

1.3. THE STUDY AREA

The area studied is the Pennine region of Central England (Figs.1B,2A & 2B). It is dominantly in the counties of West Yorkshire and Lancashire, though it extends also to the following counties; Northern and eastern parts of Greater Manchester, northern parts of Derbyshire and western parts of south Yorkshire. Its overall areal coverage is some 3000 sq kms. The Ordinance Survey 1:50,000 topographic maps, sheets 103, 104, 109 and 110 and the Institute of Geological Sciences (I.G.S.) Geological sheets 68, 69, 76, 77 and 86 cover the area.

Physiographical Features

The prominent physiographical features include areas of high moorland which occur either as plateaux or ridges or those of lowland occurring as synclines. There are also coal bearing areas which are termed coal basins. The features are dependent on geology and some of the following, which are the dominant ones, will be discussed in section 1.4. dealing on Structures: Pennine Anticline, Mossley Anticline, Rossendale Anticline, Pendle Marocline, Ribble Fold Belt, Burnley and Laneshaw synclines.

Nature of Exposures

Streams provide many useful exposures. In fact most of the complete successions of the rock units are provided by streams. The major weak point of the stream exposures is that they often lack significant lateral extent. Stone quarrying has been an important industry in the study area as shown by the large number of quarries - which often provide good exposures. Most of these quarries are disused. The limitation of many of these quarries is that they often provide short and two dimensional rock sections. A few working quarries however are vital because, not only do they provide large sections but in many cases they also portray three dimensional views of their rock sections. Road cuttings, and hill sides provide laterally extensive exposures. Numerous boreholes made, particularly around Huddersfield and Bradford areas, provide good subsurface successions of the Marsdenian rocks. The details of the exposure types are given in section 2.2.

1.4. STRUCTURE OF THE AREA

In the eastern half of the study area, embracing the districts of Bradford in the North to Glossop in the South, the principal structural elements are the Pennine Anticline, the Mossley Anticline and the Alport Dome (Fig. 3).

The Pennine Anticline is asymmetrical, with a steep westerly limb and a gentler eastern flank. The asymmetry is however less pronounced in the areas south of Todmorden (SD 938246) than in those places to the north. Much of the ground along the tract of the anticline attains heights of about 300m to some 600m, compared with common height range of 30m to some 300m on the eastern ground and 70m to some 500m in the western flank. The oldest, strong Millstone Grit beds usually crop out near the axis while successive younger beds are generally exposed at lower altitude towards the east. Consequent to the low uniform easterly dip and the frequent alternation of hard and soft beds, the sandstone beds form prominent escarpments called 'Edges', 'Scouts" or "Scars".

Faulting is severe, especially along the axis of Pennine Anticline where the faults commonly trend north to south, following the axial trend of the anticline. The fault trends in the rest of the areas can be generally referred to the following two main systems:

a. Faults trending NW to SE. These appear to dominate generally.

b. Faults trending NE to SW.

Several minor faults diverge considerably from these two dominant orientations, a common tendency being to follow a more nearly east and west trends. Consequently, localities displaying rectangular systems of fracture are encountered. The Alport dome which is the most northerly manifestation of the gentle folding of the Derbyshire Dome of the south is responsible for the sudden widening of the Millstone Grit outcrop south of Holmfirth (Bromehead _et al._, 1933).

In the western half of the study area covering the districts of Rossendale anticline, Clitheroe and Nelson, the dominant structural elements consist of the following: the Rossendale Anticline, the Pendle Monocline, the Ribblesdale fold belt, the Pennine Anticline, the Burnley and Laneshaw synclines (Fig. 3).

The Rossendale Anticline gives an area of prominent high ground with several sub-features, each of which controls the outlook of the topography. One of its very prominent sub-features called "The Central Plateau" is a roughly circular plateau composed of horizontally lying beds and virtually occupies the centre of Geological Map Sheet 76.

Ribblesdale fold belt consists of a complex series of anticlines and synclines which is located north of Pendle Monocline and has the same trend as it.

Burnley and Laneshaw synclines lie between the Rossendale Anticline and the Pendle Monocline.

Like the structures of the eastern half, structural elements of the western flank are also intimately associated with faults, whose trends are similar to those of the eastern half.

Faulting and folding in the study area appear to be intimately connected and may have been contemporaneous (Bromehead et al. 1933; Wray et al. 1930; Stephens et al., 1953). The faults are probably of the same type and may have resulted from torsional movements set up by unequal or irregular uplifts along the line of the main Pennine axis (Wray et al., 1933). Pennine uplifts, together with other large scale complex compressional tectonic structures like the Ribblesdale fold belt, Pendle monocline, Burnley and Laneshaw synclines and various other associated faults were probably generated by the orogeny associated with latter stages of the Armorican earth movements duing the late Palaeozoic times (Earp et al. 1961).

1.5. PREVIOUS RESEARCH

Previous research publications that concentrated on the Marsdenian are few. Some workers recorded specific though isolated observations from the Marsdenian stage during their regional studies of the Millstone Grits. Many other workers made generalized remarks on the overall Millstone Grits, implying indirectly an involvement of the Marsdenian sequence. Certain works on the Millstone Grits are included here even though they are pre-Marsdenian if they are considered relevant precursors for subsequent works on the Marsdenian sediments. Since the number of works involved is large, it is considered that their presentation in a tabular form as shown below will be more convenient to the reader. The works are discussed chronologically, firstly on a regional basis, which here constitutes those relevant works on the Millstone Grit, and secondly on the particularized aspect of the Marsdenien Stage.

REFERENCE	DESCRIPTION
STRATIGRAPHY	
Millstone Grit Regional Studies	
Whitehurst, J. (1778)	Proposed the term Millstone Grit (though he termed it Millstone Gret), for the coarse-grained to pebbly quartzose, angular to rounded sandstone which lies uppermost in his section of the rock strata compiled for the areas around River Derwent. The following rock strata were sketched by him in his Fig.6

Plate 1, as occurring below a line which represents the surface of the earth (list is from top to bottom):

1.	Millstone Gret:	Sandstone
2.	Shale or Shiver:	Clay
3.	Limestone:	Marble substance
4.	Toadstone:	Black lava-like substance
5.	Limestone:	Marble substance
6.	Toadstone:	Black lava-like substance
7.	Limestone:	Marble substance
8.	Toadstone:	Black lava-like substance
9.	Limestone:	Marble substance

Smith, W. (1819) — Employed the name Millstone Grit, as a geological term, to the series of sandstone and mudstones lying between the Carboniferous Limestone and the Coal Measures.

Binney, E.W. (1839) — First to regard the top of the Huddersfield White Rock as the uppermost limit of the Millstone Grit.

Hull, E. (1864) — Contends that Green proposed the term Kinderscout Grit for the gritstone which was mistaken as the base of the Millstone Grit because the gritstone caps the Kinder Scout moor in the Peak District.

Hull, E. & A.H. Green (1864) They numbered the Grits within the Millstone Grits in the order in which an oil-well logger would number them. From the top downwards the rocks were numbered "First" to "Fourth" (Table 1).

Basis of this terminology: The Rough Rock and the Kinderscout were considered the more distinctive members of the Millstone Grit. The Rough Rock was regarded as the "First Rock", and Rough Rock Flags, the "Second Rock". The Kinderscout Grit which was erroneously correlated as the lateral equivalent of the Skipton Moor Grit was considered as the "Fourth Grit" whereas the variable series of sandstone and Mudstones between the distinctive members were called the "Third Grit" or the "Middle Grit".

Bisat, W.S. (1924) Established a zonal classification of the Namurian rock sequence of the North of England based on goniatites (Table 2). Contends that the marine band overlying Huddersfield White Rock marks a distinct faunal change from genotype Reticuloceras to genotype Gastrioceras and so should mark the upper limit of the Millstone Grit Series. This work marks a major breakthrough in the stratigraphic thinking in many parts of the world, particularly North of England where the work remains invaluable in correlating the sandstone and other barren strata which lie between the goniatite-bearing horizons.

Hudson, R.G.S. & G.Cotton (1943). Redefined the stage divisions of Bisat (1928) into a scheme of zones and subzones (Table 2). Proposed the terms Arnsbergian and Pendleian. Contend that fossils of the Namurian mudstone are restricted to marine bands.

Hudson, R.G.S. (1945) Instituted Namurian Goniatite Zones of equal value, where zonal indices in any one stage are of the same genus, thus helping to avoid the confusion caused by the choice as zonal indices of forms of different faunal phase (Table 2). Proposed the term Yeadonian.

Stephens _et al._, (1953) Remapped the area around Bradford and Skipton on Sheet 69 (New Series) and wrote an accompanying memoir to it (Table 1).

Earp _et al._ (1953) Re-mapped the area around Clitheroe and Nelson on Sheet 68 (New Series) and wrote a memoir to accompany the sheet (Table 1).

Ramsbottom _et al._ (1962) Redefined formally, the zonal boundaries of Carboniferous rocks at the bases of individual cycles in which the diagnostic goniatites occurred, instead of at the actual occurrences of the goniatite. Such redefinition hopes to make the rock zones chronostratigraphic instead of biostratigraphic which they had hitherto been, and also enables the extension of chronostratigraphic nomenclature to areas where goniatites are rare or unknown. Also, this work recognized 6 principal faunal phases (faunal elements of facies) in the Millstone Grit Series. These are (listed from top to bottom) (1) Fish phase (2) Planolites phase (3) Lingula phase (4) Mollusc Spat phase (5) Anthracoceras or Dimorphoceras phase (6) the typical thicker-shelled goniatite phase. Although all these phases do not necessarily occur in any one cycle of faunal phases, the order in which the phases are numbered is that in which they occur in the cyclic succession. It may also become the order of increasing salinity of environment, though increasing depth of water may have been another factor.

Ramsbottom, W.H.C. (1966) Established useful regional correlations of the Namurian rocks of the Pennines.

Ramsbottom, W.H.C. (1969a) Refined Bisat (1924) goniatite zones into a sequence of goniatite stages and zones. Provides stratotype for the Namurian stages in the Central Pennines.

Ramsbottom, W.H.C. (1969b)	Contends that goniatite bands should be chrono-planes since they are of wide geographic extent and are of short duration. Contends also that a new goniatite fauna inhabited the Central Pennine areas after every 200,000 years and that the duration of each goniatite horizon is probably less than 10,000 years.
Ramsbottom, W.H.C. (1974)	Synthesised the various works of Bisat and subsequent authors into a modern, refined and widely used scheme of stages, principal goniatites, transgressions and regression of major and minor cycles and principal lithostratigraphic units (Table 2).
Ashton, C. (1974)	Elucidated the biostratigraphy of Namurian R_1 and R_2 sequences of the North Staffordshire basin. The R_2 succession was studied up to and including the _R. bilingue_ typical. In revising the _R. nodosum_ zone of the R_1 sequence, she recognized 5 beds with distinctive fauna. While re-examining R_2 fauna she discovered 3 new _R. gracile_ variants and 3 new species within the _R. bilingue_ fauna. She established and used 8 thin kaolinized ash bands in correlating her rock successions.

Ramsbottom, W.H.C. (1977) Recognized 11 major chronostratigraphic cycles in the British Namurian, by combining lithologic correlation based on cycles and recognizing that new goniatites and their associated fauna occur after unusual regressive periods. The recognition of such time-stratigraphic zones clarified the existence of important lacunae in the Namurian succession in different areas. Contends that each of the 11 chronostratigraphic cycles involves a basal muddy sequence containing several sub-cycles with their thick sandy phases regarded as representing sea level fall which allowed the mainly fluviatile sandstone to reach far into the basins.

Ramsbottom, et al. (1978) Produced detailed and useful regional correlation of the Silesian rocks in the British Isles utilizing goniatites primarily and other additional means like conodonts, miospores, plant macrofossils, bivalves (both marine and non-marine); lithology (over short distances) and parastratigraphic units.

Ramsbottom, W.H.C. (1979) Contends that the pattern of Namurian sedimentation in NW Europe involves the slow but progressive and pulsed transgression, followed by a rapid regression. Individual pulses (cyclothems) of transgressions caused big changes in coast line for rather small rises of sea level, while major regressions at the mesothemic boundaries were probably caused by only a few metres, seldom exceeded one or two tens of metres, of fall of sea level due to the flat topography which probably existed during the Carboniferous. Rarity of channeling was regarded as indicating the small amount of sea level lowering during regression. Each of the 11 mesothemic cycles involved occupied the average duration of 1.1 - 1.35m. years and the thick Namurian sandstone within each cycle must have been deposited during one cyclothem. Coals accumulated quickly and not slowly as is generally accepted.

Studies, with Marsdenian stage emphasis

Green, *et al*. (1871) — Subdivided the 4 sandstone units within the Marsdenian stage and lettered them A, B, C, D, from the bottom upwards (Table 1, compare with Mem. Geol. Surv. 1875).

Hull, *et al*. (1875) — Subdivided the 4 sandstone units within the Marsdenian stage and lettered them, A, B, C, D, from the top downwards and the shale taking the letter of underlying rock. (Table 1, note that this order of lettering conflicts with that of Mem. Geol. Surv. 1871).

Green *et al*., (1878)	Introduced the term Middle Grit, for all the sandstone beds between the Kinderscout Grit and Rough Rock.
Dakyns, *et al*. (1879)	Introduced the term Guisely Grit for the sandstone unit occurring between *Reticuloceras bilingue* and *R. superbilingue* in the area between Skipton and Bradford.
Davis, J.W. & F.A. Lees (1880)	The trace fossil, which is commonly seen in fine-grained sandstone and which is presently interpreted as *Olivellites* was recorded by them in Halifax district.
Jones, R.C.B. (1924)	Found the actual exposure of the fossiliferous mudstone separating the Fletcher Bank Grit from the Helmshore Grit, in River Ruddlesworth, several miles west of Danven.
Wright, *et al*. (1927)	Postulates the rhythmic nature of sedimentation of the Millstone Grit and the Lower Coal Measures. Remapped the Rossendale Anticline on Sheet 76 and wrote a memoir to accompany the sheet (Table 1).
Bisat, W.S. (1928)	Introduced the term Marsdenian as a stage name while subdividing the genus zones as stages and equating them with lithologic units.

Wray, *et al*. (1930)	Adopted local names derived within the area where each lithostratigraphic unit of the Middle Grit is developed for the naming of the unit. For instance the grit that occurs about 18m above *R. bilingue* typical and often well developed and exposed on Midgley Moor is termed "Midgley Grit", while the names "Nab End Sandstone" and "Beacon Hill Flags" are given to the sandstone unit overlying *R. bilingue* late in the north and south respectively in the Huddersfield-Halifax area. Remapped the area around Huddersfield and Halifax on Sheet 77 and wrote an accompanying memoir to the sheet (Table 1).
Bromehead, *et al*. (1933)	Introduced the name Heyden Rock for the rocks of Pule Hill Grit equivalents which are well developed and exposed around Heyden Valley area. Remapped the area around Holmfirth and Glossop on Sheet 86 and wrote a memoir to accompany the sheet (Table 1).
Dean, T. (1934)	Recognized that the *R. gracile* band in a borehole section at Snail Green, Rombald's Moor is separated into two distinct sub-bands by Ostracod-bearing shale which is approximately 1m thick. He maintains that "detailed collecting from these 2 bands (the sub-bands) revealed distinct faunal variation as the beds are traced upwards".

Hudson, R.G.S. & W.W. Black (1940).	Recorded 10cm thick coal on top of East Carlton Sandstone in Carlton Moor borehole.
Stephens, *et al*. (1942)	Found 3 variants of *R. gracile* goniatite in the Rombald's Moor area plus an additional fourth variety which is widely umbilicate.
Edwards, *et al*. (1950)	Introduced the term "Brandon Grit" for those grits of Pule Hill Grit equivalent occurring eastwards from Carlton Moors in the Guiseley area.
Wright, *et al*. (1927)	Added a further mutation, known as *R. metabilingue* or *R. superbilingue* early to Bisat's (1924) succession. Commented on the relationship of *R. gracile* late and *R. gracile* typical, because they found that the typical form occurring near Middle Mickle Hey in Blackburn, appears to occupy a higher stratigraphic level than the *R. gracile* late of the Todmorden district, whereas the same late form occurs close below the lowest *R. bilingue* early at Pule Hill. Faced with this perplexity they remarked as follows: "..... one can only quote Mr Bisat's remark that it is not impossible that both early and late mut. alpha are merely local variants of typical mut. alpha".

SEDIMENTOLOGY

Millstone Grit. Regional Studies

Phillips, J. (1836)	Made the first facies analysis of Millstone Grit. He established the following facies (1) Shale (2) Grey Beds (3) Flagstone (4) Ganister (5) Gritstone (6) Ironstone (7) Coal.
Sorby, H.C. (1859) Green, A.H. (1878) Gilligan, A. (1919)	Pioneers of sedimentary research on the Millstone Grit. They contend that the sandstones and mudstones of the Millstone Grit are of freshwater or estuarine origin. Both Sorby and Gilligan are additionally interested in the source of the sedimentary material that constituted the Millstone Grit. Sorby experimented on sedimentary structures and compared the cross bedding which he generated with that of the Millstone Grit. After extensive research, both Sorby and Gilligan separately concluded that the Millstone Grit clastics are derived from a crystalline terrain located northeast of the basin.

Wright, _et_ _al_. (1927)	Postulates the rhythmic nature of sedimentation of the Millstone Grit and the Lower Coal Measures. Remapped the Rossendale Anticline on Sheet 76 and wrote a memoir to accompany the sheet (Table 1).
Trotter, _et_ _al_. (1951)	Described the Namurian in terms of sedimentary facies representing Continental and Estuarine river deposits.
Allen, J.R.L. (1960)	First to recognize turbidites in the Namurian of the Central basin. This work plays a leading role in the present phase of sedimentary research in the basin.
Shackleton, J. (1962)	Carried a very extensive palaeocurrent study on the Namurian. Tracing the Rough Rock horizon throughout the Central Pennines, he found a regionally consistent pattern of palaeocurrent to be present, indicating water movement from NE to SW. Marked divergences occurred only locally in parts of south Yorkshire, where current was seen to be form the east to the SE.
Holdsworth, B.K. (1963)	Investigated the Lower and Middle Namurian sequences in the North Staffordshire Basin. He contends that this area is dominated by thin turbidite sequences. For instance he considers sediments of the Pendleian Stage

(E_1) to be "late-stage sediment differentiates of turbidity currents". He postulates a rapid subsidence to account for the presence of turbidites at the base of his sequence. He contends also that the first widespread appearance of coarse, shallow water sandstones occurred in the R_{2b} zone.

Wright, M.D. (1964, 1967)	Suggested that the cross-bedded sandstone of the R_1 succession in Marsden and Longdendale area, were deposited in large fluvial channels and that the finer and rippled sandstone were of tidal and estuarine origin, whereas the mudstones must have been deposited in embayments and other areas of shallow sea close to the delta.
Reading, H. (1964, 1971)	Reviewed regional aspects of the Millstone Grit sedimentation and contends that the R_{1c} sediments were deposits of the second of the two major periods of infilling of the Central Pennine Basin, the first having deposited the Skipton Moor Grits in E_1 times.
R.G. Walker (1965, 1966)	Established the following environments in Shale Grit, Grindslow Shale and Kinderscout Grit of North Derbyshire: Submarine Fan, Slope and Delta top.

Collinson, J.D. (1967)	Established 17 facies within the Grindslow Shales and Kinderscout Grit in the area north of Derbyshire Dome and contends that the Grindslow Shales represent the main southwards advance of the R_{1c} delta slope and delta top environments across the area, while the Upper Kinderscout Grit represents deposit of laterally migrating rivers.
Collinson, J.D. (1968)	Contends that the large-scale cross-bedding which he found in the Kinderscout Grit (Namurian, R_{1c}) of the southern half of the Central Pennine Basin, England, represent "deltaic sedimentation units", while the Medium-scale cross-bedding overlying the large-sets represent the "topset member of the sedimentation units" (see McCabe 1977).
Collinson, J.D. (1969)	Grouped the 14 facies which he recognized in the Grindslow Shales and the Kinderscout Grit of Northern England into the following five facies associations (from bottom upwards): (1) Slope (2) Interdistributary Complex (3) Deep Fluviatile Channel (4) Deltaic Sedimentation Unit (5) The Migrating Fluviatile Channel.

Collinson, J.D. (1970a) — Proposes that massive bedded sandstone facies can form from "a rather rapidly decelerating fluviatile current, depositing from suspension and/or a traction carpet and possibly associated with antidune bedforms". Differentiated between his "Deep Fluviatile Channels" restricted to the upper part of the Grindslow Shales (Delta top deposits) from his "Turbidite Filled Channels" confined to the delta slope deposits of the lower part of the Grindslow shales. Contends that these channelized turbidites are generated during floods, when the sediment laden traction currents developed autosuspension at the top of the slope and flowed down the slope.

McCabe, P.J. (1975) — Made a detailed sedimentary study of the Kinderscout Grit between Wharedale and Longdendale. Grouped the 22 facies which he established in the area to the following 3 major assemblages (listed from bottom upwards): "A", which he interpreted as the deposits of submarine fans; "B" which represents delta slope sediments and "C" interpreted as a delta top sequence with the large channels at the base being the main delta distributaries.

McCabe, P.J. (1977) — Renamed the large-scale cross-beds of Collinson (1968) to Giant cross-beds and reinterpreted these as the product of side-attached, alternate bars of delta distributaries.

Baines, J.G. (1977) — Undertook a regional sedimentary analysis of the Skipton Moor Grit, within which he established the turbidite, slope and delta top associations. Described 25 ichnogenera from the Skipton Moor Grit and used them to refine palaeoenvironmental and bathymetric reconstruction.

Johnson, E.W. (1981) — Recognized syndepositional instability within the deltaic sediments of a prograding Namurian (Arnsbergian, E_{2a}) delta, in the western Bowland Fells, north Lancashire as illustrated by slumps and debris flow; and suggests that tectonics may be controlling the regional variation in sediment thickness.

Studies in area of interest and its vicinity, with emphasis on the Marsdenian Stage

Mayhew, R.W. (1967) — Recognized the following 2 major facies in his Marsdenian Grits (Ashover and Chatsworth Grits) of south east Derbyshire: A lower non-pebbly trough cross-bedded sandstone which he interpreted as "anastomosing distributary channel mouth bars in a deltaic region" and an upper Pebbly Facies dominated by planar cross-bedding which represented "transgressive fluvial deposits of a coastal plain environment".

Benfield, A.C. (1968)

Established the following 3 major units within his Huddersfield White Rock (Namurian R_{2c}) cyclothem exposed in the Central Pennines: (listed from bottom upwards) (1) The mudstone member interpreted as a delta-slope sediment, (2) The Sandstone Member which comprises of 8 facies of which two facies constitute channel levee and back swamp deposits; one of the remaining 6 "sheet-sandstone assemblage" represent barrier beach and lagoon deposit and the remaining 5 facies were identified with the various depositional environments of a prograding deltaic distributary, (3) The Seatearth-Coal-Clay Shale Complex which was deposited in a transgressive marsh.

Jones, C.M. (1977)

Recognized the presence of Deep Water, Delta Slope, Delta Top and Delta Margin Associations in the Roaches Grit Group (Namurian R_{2b}) in North Staffordshire (S.W. Pennines) and adjacent areas.

Collinson, *et al*. (1977) — Established the presence of a thick turbidite sequence of some 240m thickness which is dominated by units of mainly thicker bedded turbidites up to 40m thick, within the Namurian R_{2a} period in a tunnel driven west of Blackburn. Upwards, above the band of *R. bilingue*, this turbidite deposit grades through delta slope sediments to the coarse-grained fluviatile sandstone of the Delta Top environment.

Kerey, E. (1978) — Made a detailed sedimentologic analysis of the Chatworth Grit (Namurian R_{2c}) in the Goyt Chapel-en-le-Frith area, and recognized 9 lithofacies which he suggested to have an overall regressive sequence of Prodelta-Delta front-Delta Top. The Siltstone of his Delta Front Association has *Carbonicola*.

1.6. METHODS OF STUDY

1.6.1. FIELD METHODS

The exposure of streams, quarries, road cuttings and hill sides discussed in section 1.3. were measured in detail with tape and/or Abney level, depending on the nature of exposure, and drawn up on varying scales depending on the complexity of the sequence. Where Abney level was used in the measurement, it was set to the dip of the rock. Abneys were particularly useful in gaps of exposures and in some thick units with irregularly exposed vertical faces, Where the lateral and vertical extents of the exposure are large, 2 to 5 vertical sections were made, and field sketches and extensive photographing facilitated the correlation of these vertical sections.Such an approach aided the understanding of the lateral extents of the various suites of vertical sequences encountered at the different parts of such large exposures. Grain size was judged with the aid of a portable scale of grains of different seive sizes, corresponding to a Wentworth scale. Colour assignment was based on the Geological Society of America (G.S.A.) rock colour chart (Goddard, 1970). On the whole, 75 vertical sections were constructed from field data.

Numerous palaeocurrent structures, involving sole marks and cross stratification were recorded for palaeocurrent determinations. Details of the methods used are given in section 6.1.1. In some cases, particularly in the study of the cross laminated rocks, it was necessary to trace the outline of the cross laminae direct from the rock face. Such traces were made with a felt-tip pen on a transparent plastic sheet of paper glued to the rock face with 'Blue-tack'. The orientation of the long axes of ichnogenus Pelecypodichnus and plants were also recorded to determine if they are current orientated.

1.6.2. Laboratory Methods

Specimens collected from the field from all facies were examined in the laboratory. Thin sections of most types were cut and examined for confirmation of grain size, and limited compositional analysis. This laboratory information was used to refine the field measured section.

19 subsurface vertical sections were also made from the well documented borehole data obtained from I.G.S. Leeds.

The vertical sections made from the field data were combined with the surface vertical sections to produce stratigraphical sections for the different areas in the Central Pennine Basin. These are discussed in Chapter 2. They were also utilized in the reconstruction of palaeoenvironments and palaeogeography as are discussed in Chapters 4 and 6 respectively.

CHAPTER 2: STRATIGRAPHY

2.1. BIOSTRATIGRAPHY

The Marsdenian stage, in Northern England, is rich in goniatite bearing mudstone units, popularly called Marine bands. Each band is characterised by its distinctive fauna, though goniatites of the genus *Reticuloceras* are the most abundant and characteristic members of each band. In each band one goniatite form often predominates to such an extent that the bands identification is greatly facilitated even though most specimens are fragmentary. Based on these observations, Bisat (1924) instituted a faunal zonation (Table 2) which remains invaluable for any meaningful stratigraphic work in Northern England. Later works (Bisat 1928, 1932; Hudson and Cotton 1943; Hudson 1945; Ramsbottom 1969, 1974, 1978; Ashton 1974) modified and extended Bisat's (1924) scheme (Table 2).

The Marsdenian goniatite bands generally accepted as stratigraphically significant are diagrammatically shown in Figure 4. They consist of bands of *R. gracile* early, *R. gracile* typical, *R. gracile* late, *R. metabilingue* and *R. superbilingue* typical. The distinctive characteristics of each of these goniatite bands, and their faunal assemblages are discussed by Bisat (1924), Ramsbottom *et al.* (1962) and Ashton (1974).

The occurrence and distribution of these bands are plotted in Figures 6 - 10. For purposes of discussion of these bands, the study area is divided into 5 areas whose boundaries almost coincide with the Institute of Geological Sciences 1 inch geological map. The areas 1-5 are shown in Figure 5. The *R. gracile* band is discussed first. The other bands are discussed systematically in

Table 1. CORRELATION CHART SHOWING NOMENCLATURE OF MARSDENIAN LITHOFACIES AND ADJACENT NAMURIAN UNITS

Stages	Group	Old classification and nomenclature	Holmfirth & Glossop Sheet 36	Huddersfield & Halifax Sheet 77	Bradford & Skipton Sheet 69	Rosendale Anticline Sheet 76	Clitheroe & Nelson Sheet 68
			Bromehead C.E. et al. 1933 NW Central SE	Wray D.A. et al. 1930 North / South	Stephens, J.V. et al 1953 West & Centre/East	Wright, W.B. et al. 1927 Blackburn / Todmorden / Central & SW	Earp, J.R. et al. 1961
YEADONIAN		1st Grit / 2nd Grit	Rough Rock & Rough Rock flags	Rough Rock / Rough Rock Flags	Rough Rock / Rough Rock Flags	ROACH ROCK / ROUGH ROCK / ROUGH ROCK	ROUGH ROCK GROUP
	ROUGH ROCK GROUP		Shales (with Upper Haslingden Flags in Lancashire)	Shales with Moorside Flags & thin coal	Shale with G.cumbriense Shale with G. cancellatum	UPPER HASLINGDEN FLAGS G.cumbriense max LOWER HASLINGDEN FLAGS G.cancellatum max R. ret. mut Y exit,	UPPER HASLINGDEN FLAGS G. cancellatum
MARSDENIAN	MIDDLE GRIT GROUP	3rd Grit	Upper Meltham Coal (Holcombe Brook Coal in Lancashire)	Upper Meltham Coal	Coal		
		D^x A^+	HUDDERSFIELD WHITE ROCK Holcombe Brook Grit in Lancashire)	HUDDERSFIELD WHITE WARLEY ROCK BARKISLAND FLAGS	HUDDERSFIELD WHITE ROCK	HOLCOMBE / BROCK & BROCK-BOTTOMS SANDSTONES	HOLCOMBE BROCK SANDSTONE
			R. ret. mut Y	R. ret mut Y #	R. ret mut Y	R. reticulatum, mut Y (entry & max)	R. superbilingue
		C^x B^+	BEACON HILL FLAGS ††	NAB END SANDSTONE / BEACON HILL FLAGS	GUISELEY GRIT Rough Holden Coal	HAZEL GREAVE GRITS	HAZEL GREAVE GRIT
			R. ret late mut B ††	R. ret mut B and B (late)	R. ret mut B (late)	R. reticulatum, mut B late form)	R. bilingue
						HELMSHORE GRIT Estuarine Band	
		B^x C^+ Main 3rd	PULE-HILL GRIT / HEYDEN ROCK / REVELIN	MIDGLEY GRIT / PULE HILL GRIT	WOODHOUSE GRIT / BRANDON GRIT	REVIDGE GRIT / GORPLEY GRIT / FLETCHER BANK GRIT	REVIDGE GRIT, GORPLEY GRIT
					Lingula Band	M.B. R.ret mut B early forms) / R.wrighti	R. bilingue
					BLUESTONE		BLUESTONE
		A^x	Shale with R.bilingue	Shale with R.bilingue (near shale base)	Shale W/ R. bilingue Coal		
		D^+	READYCON DEAN SERIES	SCOTLAND FLAGS ☆ / READYCON DEAN SERIES ☆	EAST CARLTON GRIT		
			R. gracile (late)	R. gracile, R.gracile (late)	Shale W/ R. gracile	M.B. R.gracile late) / R.gracile	R. gracile
Kinderscoutian	Kinderscout Grit Group	4th Grit	Kinderscout Grit	Upper Kinderscout Grit	Kinderscout Grit	Kinderscout Grit / Upper Kinderscout / not proved	Kinderscout Grit

$^+$Mem.Geol. Surv. 1875. ††Absent in the Central area (around Black Hill & Holme areas). *This work. ☆Grit D of the older writers on this district.

^{x}Mem.Geol. Surv. 1871, p.4.

To the west band changes into a Lingula band on the N. side of Todmorden and the sigma band disappears further south.

Table 2. CORRELATION CHART SHOWING GONIATITE ZONES AND SUBZONES WITHIN THE MARSDENIAN STAGE

STAGE	INDEX	Bisat 1924 Zone	Hudson 1945 INDEX	Hudson 1945 Faunal succession	Hudson 1945 Zone	Hudson & Cotton 1943 Zone	Hudson & Cotton 1943 Subzone	Ramsbottom INDEX	Ramsbottom 1969 Chronozones	Ramsbottom 1974/1978 Subchronozones	Ashton 1974 INDEX	Ashton 1974 Chronozones	Main leaf	
		R.ret mut gamma (R.super-bilingue)	R2ciii	G.sigma						G. ?sigma				
			R2cii	G. lineation R.superbilingue	R.super-bilingue	R.super-bilingue	R.super-bilingue	R2c	R.superbilingue					
			+ R2ci	R.bilingue late form R. eometa-bilingue (dominant)			R.meta-* bilingue			R.superbilingue				
	R2		R2bii	R.metabilingue (now R.eometa-bilingue) R.bilingue late			R.bilin-gue late form			R.bilingue(late) or R.metabilingue				
			PULE-HILL GRIT										THIRD	Reticulatum sp. nov.
													SECOND	Reticulatum sp. nov.
		R.ret mut Beta (R.bilingue)	R2bii	R.bilingue &/or R.bilingue late form (R.Wrighti)	R.bilin-gue	R.bili-ngue		R2b	R.bilingue	R.bilingue	R2bii	R.bilingue	FIRST	R.bilingue (Bisat) R.sp.nov. of R.bilingue group R.bilingue S.L.
MARSDENIAN							R.bilin-gue				Between R.bilin-gue Early & R. bilingue		-	Reticuloceras sp.nov.
			R2bi	bilingue &/or R.bilingue early form plus E. proteum						R.bilingue (early)	R2bi	R.bilingue (early)	Not named	R. Wrighti Hudsonoceras ornatum R.bilingue (early)
														R.retiforme sp.nov. (upper)
		R.ret mut alpha (R.Gracile)	R2aii	R.gracile ss	R.gracile	R.gracile	R.gracile	R2a	R.gracile	(not divided)	R2a	R.gracile	Upper	R.graciloides (=R.gracile late) R.late lirife sp.nov.
			R2ai	R.ret late mut alpha R.gracile R.ret early mut alpha			R.aff. gracile						Lower	R.gracile R.gracilingue (=R.gracile early)
														Rretiforme sp. nov. (lower)

+Has not often been recorded from Yorkshire.

*Both Wright et al (1927) & Stephens et al (1953) recognize R.metabilingue at this level (they refer to it as Early mut gamma).

stratigraphical order. In these discussions, only the specific names of the goniatites as defined by Bisat (1924) are used.

Tables 3 - 8 show the thickness of each of the marine bands, the height of occurrence of the band above a specified prominent underlying grit or marine band, the type of fossil in the mudstone below the marine band and other relevant data pertaining to the goniatites. Most of the data used in the plots and the tables are derived from memoirs of the Geological Survey of Great Britain (I.G.S.), explaining sheets 86, 77, 69, 76 and 68. The rest of the data are based on the observations of the author and the works of several other referenced authors.

2.1.1. The Reticuloceras Gracile Bands R_2a

The Reticuloceras gracile bands are made up of three bands namely the *R. gracile* early, *R. gracile* typical and *R. gracile* late. However, uncertainty still remains concerning the precise stratigraphical identity of these bands, particularly on a widespread basis. While the bands appear simple and distinctive in many places especially in areas 1, 2 and 4, they also exist together in some other areas, such as in area 3.

The three bands are however plotted together in one map, with the expectation that such a presentation will portray whatever inter-relations exist among them.

Occurrence and Distribution

The distribution of *R. gracile* early is very patchy and appears limited to only areas 2 and 3. Contrastingly, *R. gracile* typical is widespread and occurs in all areas except in the southwestern and

Table 3A Bands of R. gracile variants

Area Number	Base Map Locality Number	Locality	Thickness of Marine Band (M)	Height of occurrence of Marine Band above Upper Kinderscout (M)	Type of Fossil in Mudstone below Marine Band	National Grid Reference	Type of R. gracile band	Thickness (M) between Upper Kinderscout and Scotland Flags in the area. Other observations	Source of Data
5	39	Sabden Brook	1.5	70	None	SD 747346	Typical Late	75m (thickness between R.gracile and R.bilingue in Sabden Brook	Author's
3	23	Rag Clough	3.3	0.45	Plant	SE 014338	Typical " SL " SL	Generally varies between 12-21m though at their outcrop near Bramhope it decreases to 3m or less	Author's & Stephens et al. (1953)
	28	Snail Green	3.3	NM	NM	SE 118425	Typical		Deans (1934)
	28	Snail Green	2.7	NM	NM	SE 118425	Typical		' "
	26	Park Wood Quarry	NM	1.8	NM	SE 066407	Typical & Late		Stephens et al. (1953
	26	Park Wood Quarry	NM	6.3	Gracile Typical & Late	SE 066407	Typical		" " " "
	29	Kirk Lane Dyeworks	6.5	NM	NM	SE 203410	Typical & Late		" " " "
	30	Horsforth Waterworks Bore	5.4	3.3	None	SE 231411	Typical		" " " "
2	17	Dry Clough	0.9	4	None	?SD 989178	Late	The mudstones are generally 18-42m thick	Wray et al. (1930)
		Shot Scar	NM	6	NM		Late		" " " "
	11	Hard Head Clough	0	4	None	SE 025137	Late		" " " "
	14	Quarmby Clough Mill Bore	1.8	4.5	None	SE 108170	Early R.ret type		" " " "
	13	Mold Green Bore	6	1.2	Plant	SE 158164	Typical transitional R.ret type		" " " "
1	10	Mount Road Outcrop Marsden	NM	0.5	NM	?SE 033012	Late		Bromehead et al. (1933)
	9	Shiny Brook	3.6	0.6-1.8	None	SE 061071	Late Typical	Usually 13-21m	" " " "
	6	Howel's Head	NM	0	None	?SE 050029	Typical		" " " "
	5	Crowden Great Brook	6	0.9	"Flattened fossils"	SE 062031	Typical		" " " "
	5	Crowden Great Brook	-	-	"	SE 062031	Typical		" " " "
	4	Heyden Brook	NM	0	NM	SE 096026	Typical		" " " "
	-	Far Small Clough	NM	6	NM	-	NM		" " " "
	2	Little Don	2.7	2.4	Plant	?SK 190990	Typical		" " " "
	1	Small field	1.5	2	None	SK 230946	Typical		" " " "

Explanation for Tables 3 to 5

NM = Not Mentioned
R.ret = Reticuloceras reticulatum
U.K. = Upper Kinderscout
L = Lower Band
M = Middle Band
U = Upper Band
R.sup = Reticuloceras superbilingue
r = rare
Undiff = Undifferentiated

Table 3B. Bands of R. gracile variants

Area Number	Base Map Locality Number	Locality	National Grid Referemce	Type of R. gracile	Source of Data
4	37	Fletcher Bank Quarry	SD 805165	Typical	Ramsbottom (pers.comm. 1981)
	38	Mickle Hey	SD 700309	"	Wright *et al.* (1927)
	38	" "	SD 702310	"	" " " "
	38	" "	SD 695305	"	" " " "
	35	Paul Clough	SD 910278	Late	" " " "
	34	Small stream north of Colmholme Station	SD 915265	"	" " " "
	36	Ram Clough	SD 90322	"	" " " "
3	31	Carlton Moor	SE 224425	Typical (4th Band) cf.Late 2nd Band (Late 1st Band)	Hudson & Black (1940)
	21	Junction of Bent & Middle Moor Cloughs	SD 992336	Early	Stephens *et al.* (1953)
	23	Slough hole	SD 974383	Typical	" " " "
	25	Paul Clough	SE 031339	Typical + Late	" " " "
	24	Sun Hill Clough	SE 006340	" " "	" " " "
	27	Nurses Home, Victoria Hospital	SE 053415	cf.Late + a new "widely umbilicate form"	" " " "
	33	Bankfield Dyeworks	SE 207415	Aff. typical	" " " "
2	20	Dean Head Reservoir at Castle Carr	SE 021308	Typical	Wray *et al.*
	19	Ludden den Foot churchyard	?SE 040244	"	" " "
	18	Greenwood	?SD 996191	"	" " "
	18	Horse Hey	SE 001191	"	" " "
	18	Clay Cloughs	?SE008191	"	" " "
	16	Butts Clough	SE 045179	"	" " "
	12	Merry Dale Clough	SE 064144	Typical + Late + R.ret (type)	" " "
1	3	Mickledon Valley	?SK 190988	Typical	Bromehead *et al.* (1933)
	7	Rake Dike	SE 100052	"	" " " "
	8	Marsden Clough		"	" " " "

eastern parts of areas 2 and 4 respectively, which are the places of localization of R. gracile late band in these areas (Fig.6, Tables 3A & B). R. gracile late band occurs also in area 3.

The Mold Green (SE 158164) and Quarmby Clough Mill borings (SE 108170) in area 2 portray upward gradation in the types of R. gracile goniatite present. In Mold Green for instance, even though there is a mutual co-existence of R. reticulatum type form, R. gracile typical and transitional forms, the R. reticulatum type form dominates in the lower part while the R. gracile typical predominates at the top (Wray et al., 1930). Similarly at Quarmby Clough boring, both R. reticuloceras and R. gracile early co-exist in one band, but while R. reticulatum predominates in the lower portion, R. gracile early dominates in the upper parts (Wray et al., 1930). The upward variation in the type of the R. gracile goniatites in the different localities of area 3 are shown in Figure 6 . Mutual co-existence of the R. gracile goniatite variants also occurs at several localities particularly in areas 1, 2, 3, 5 (Fig. 6).

The sudden change of R. gracile typical to R. gracile late in the localities of area 2, west of an imaginary line stretching from Dean Head Reservoir at Castle Carr (SE 021308) in the north to Merry Dale Clough (SE 063144) in Slaithwaite southwards, was attributed to a lateral variation in the R. gracile fauna (Wray et al. 1930).

Discussion

The R. gracile bands, like other goniatite bands of the Central Pennine basin,are regarded as representing periods of high salinity, marine or near marine conditions in an otherwise brackish or fresh water basin.

The major reason for plotting the R. gracile variants was to determine the widespread character of each variant in order to assess to what extent the variant can serve as a stratigraphic marker. While it appears that R. gracile typical is the most widespread of the three variants (Fig. 6), its stratigraphic distinctiveness from the other two variants still remains questionable (Fig. 4). Furthermore, even though the younger variants of R. gracile goniatites occur at stratigraphically higher levels in Mold Green and Quarmby Clough Mill borings, the cases such as in Carlton Moor (SE 224425) and Park Wood Quarry where the R. gracile typical occurs above the R. gracile late makes one suspect whether there is any real age significance to this typical and late relationship.

However, based on the dual mode of occurrence of the R. gracile bands in the areas (Fig. 6), it is felt that the simple R. gracile goniatites probably passed laterally into a composite R. gracile marine band, perhaps in consequence to an amalgamation of bands.

For correlation purposes in this work, all the R. gracile bands will be treated as one composite band; after all the thickness interval between even the most widely separated variants is small and insufficient to accommodate any intervening sandstone bed as is the case in the R. bilingue bands, and only mudstone units occur in between such variants.

2.1.2. The Reticuloceras Bilingue Bands R2b

There are three distinct stratigraphic levels at which forms of R. bilingue occur. The predominant R. bilingue form characterising

Table 4. Band of R. bilingue (early)

Area Number	Base Map Locality Number	Locality	Thickness of Marine Band (M)	Height of Occurrence (M) of Marine Band above R. gracile band	Type of Fossil in Mudstone below Marine Band	National Grid Reference	Thickness of mudstone between Scotland Flags (P) and Pule Hill Grit (P) in the area. Other observations	Source of Data
4	46	Fletcher Bank Quarry	NM	NM	NM	SD 805165	180m between top gracile and base Pule Hill Grit	Ramsbottom 1966
2	44	Green Withens Edge	-	-	Lingula	SD 995170		
	45	Dry Clough	0.2	4.5	Lingula	?SD 989178		Wray et al (1933)
	42	Hard Head Clough	0	6	Lingula	SE 025137		" " "
	43	Scammonden	-	-	NM	?SE 031149		
1	41	Pule Hill (SW end)	NM	15	NM	SE 034002	Anomaly. R. bilingue late occurs in gray mudstone 6-9m above Kinderscout Grit west and northwest of Howel Head. This is a level where R. bilingue Early should be (Bromehead et al. 1933)	Bisat (1924
	40	Black Dike	1.2	7.5 above U.K.)	NM	SE 080060		Bromehead et al. (1933)

these levels are R. bilingue early, R. bilingue typical and R. bilingue late for the lowest, middle and uppermost bands respectively (Fig. 4). In contrast to the case of R. gracile bands, the R. bilingue bands are sufficiently separate for significant sandstones to occur between them in places. Since it is generally accepted that each of these bands is stratigraphically significant (Bisat 1924, Wright et al. 1927; Bromehead et al. 1933; Ramsbottom 1974) and the faunas taxonomically distinct (Wray et al. 1930; Stephens et al. 1953, Ashton 1974, Table 2), a map showing the faunal distribution within each band is made and their discussions follow.

Occurrence and Distribution

2.1.2.1. Band of Reticuloceras Bilingue Early R2bi

This form has a limited occurrence and has been reported only in areas 1, 2 and 4 (Fig. 7) where it commonly occurs 4-15m above the R. gracile band (Table 4).

2.1.2.2. Band of Reticuloceras Bilingue Typical R2bii

This band is the most widely exposed and persistent of the marine bands (Fig. 8) despite the fact that it is generally thin (Wray et al. 1930; Table 5A & 5B.In area 1 however, it is locally absent in the south-eastern parts despite the occurrence of a thick mudstone unit within its horizon (Bromehead et al. 1933). It occurs generally immediately above the first major sandstone unit (Scotland Flags p.54) occurring above the R. gracile band.

A commonly reported anomaly at this level is the occurrence of R. bilingue late band (Hudson 1945), which was also noted by Stephens

Table 5A. Band of R. bilingue (Typical)

Area Number	Base map locality No	Locality	Thickness of Marine Band (M)	Height of occurrence of Marine Band (M) above Scotland Flags	Type of Fossil in mudstone below Marine Band	National Grid Reference	Type of R.bilingue	Thickness (M) of mudstone between Scotland Flags (p.) and Pule Hill Grit (p.) in the area. Other observations	Source of Data
5	83	Sabden Brook	0.10	30	None	SD 747344	Typical	34	Authors
3	71	Park Wood	0.85	0.93	None	SE 066407	Typical(L)	12-23	Author's
	76	High Cote	0.9	NM	NM	SE 068430	Typical(M) " (L)		Stephens et al. (1953)
	79	Horsforth Water-works Bore	0.75	0.45	None	SE 231411	Late		" " " "
	74	Snail Green Bore	NM	NM	R.bilingue Typical	SE 118425	Typical(U)		" " " "
	74	Snail Green Bore	1.8	NM	None	SE 118425	" (L)		" " " "
2	62	Hard Head Clough	0	0	None	SE 025137	Typical	Common range is 18-23. However 24 at No.2 shaft of Midgley Moor	Wray et al. (1930)
	61	Old Ganister Quarry	NM	0	NM	SE 081135	"		" " " "
	64	Quarmby Clough Mill Bore	0.15	9M	None	SE 108170	"		" " " "
	63	Mold Green Bore	1.2	4.8	None	SE 158164	"		" " " "
1	57	Wessenden Reservoir	1	0	None	SE 062087	"	18-21. In the NW, R.bilingue band commonly lies directly on top of the Scotland Flags (p.) but in the centre it is separated from the Flags by several metres of barren mud-stone	Author's
	50	Withins Brook	1.8	NM	NM		"		Bromehead et al. (1933)

Table 5B. Band of R. bilingue typical

Area Number	Base Map Locality No.	Locality	National Grid Reference	Type of R. bilingue	Source of Data
4	80	Gorpley Clough	SD 923234	Typical	Wright et al. (1927)
	82	Pauls Clough	SD 910278	"	" " " "
	81	Between stream north of Hullet & Wittonstal Clough	?SD 915265	"	" " " "
3	75	Slade Lane stream section	SE 073428	Typical	Stephen et al. (1953)
	73	Riddlesden stream section	SE 080426	Lingula band	" " " "
	77	Kirk Lane Dyeworks	SE 203410	Typical (L)	" " " "
	78	Carlton Moor shales	SE 224425	O. ritida band	" " " "
	72	Saltaire Mills Bore	SE 141380	Typical	Bisat (1924)
2	65	Sowerby Bridge Railway Cutting	SE 065235		Wray et al. (1930)
	66	Triangle Railway Cutting	SE 050225		" " " "
	67	Sowerby Vicarage	SE 044233		" " " "
	69	Sattonstall Quarry	?SE 007300		" " " "
	70	Bare Clough	SE 018309		" " " "
	68	Fulshaw Clough	SE 028302		" " " "
1	56	Black Site		Typical	Bromehead et al. (1933)
	51	Crowden Little Brook		"	Author & Bromehead et al. (1953)
	53	Ramsden Clough	SE 120038	"	Author & Bromehead et al. (1953)
	59	Castle Shaw Moor		Late	Bromehead et al. (1953)
	58	Butterfly Clough	?SE 045095	"	" " " "
	54	Rake Dike	SE 097050	"	Author
	52	Hayden Valley	SE 094029	Late & typical (R)	Author
	47	Ewden Beck		Band absent	Bromehead et al. (1933)
	48	Mickeden Beck	?SK 190988	" "	" " " "
	49	Salters Brook		" "	" " " "
	55	Black Dike	SE 080060	Late	" " " "
	60	Hard Head Clough	SE 025128	R. bilingue (Undiff.)	" " " "
	47b	Westwood Clough		Typical	" " " "

et al. (1953) in areas 1 and 3. Also in area 3, the R. bilingue typical band is split into two horizons by a peculiar silty mudstone (see section 3.3.1) in areas where the silty mudstone is developed and by mudstones and sandstones where the lithofacies is not developed. The distribution of this composite band is shown in Figure 8.

2.1.2.3. Band of Reticuloceras Bilingue late R2biii

This band lies in the mudstone immediately overlying the second major sandstone unit (Pule Hill Grit p. 63) occurring above the R. gracile band. Although forms in this band range from R. bilingue typical through R. bilingue late to occasional R. metabilingue of Wright et al. (1927), R. bilingue late is commonly the predominant one, and usually, the R. bilingue typical is confined to the lower part while R. bilingue late is restricted to the upper part (Wray et al. 1930).

The R. bilingue late band is widespread, occurring in areas 1, 2, 3, 4, except in the central parts of area 1, particularly around Holme Moss (SE 095044) and Black Hill (SE 078048) where is is locally absent. Exposures of this band and even those of the R. metabilingue band are not reported in area 5.

The coexistence at this level of either the R. bilingue typical band or the R. metabilingue band as shown in Figure 9, which is based largely on the works of Stephens et al. (1953), was also reported by other workers (Hudston 1945, Ramsbottom 1974). In the northern part of area 2, particularly at localities north of Sowerby Bridge (SE 062235 a band containing Lingula mytiloides which immediately overlies the second major sandstone unit occurring above the R. gracile band is

Table 6A. Band of R. bilingue (Late)

Area Number	Base Map Locality Number	Locality	Thickness of Marine Band (M)	Height of occurrence of Marine Band (M) above Pule Hill Grit (p.)	Type of Fossil in mud-stone below Marine Band	National Grid Reference	Type of R. bilingue	Thickness (M) of mudstone between Pule Hill Grit (p.) and Hazel Greave Grit in the area. Other observations	Source of Data
4	112	Gorpley Clough	NM	3	NM	SD 915235	Typical	Variable but commonly 10-30m	Wright et al. (1927)
	113	Melling Clough	NM	3	NM	SD 915238	Typical		" " " "
	115	Hodge Clough	NM	2.5	None	SD 788194	Late		" " " "
	116	Cheesden Lumb Mill	0.6	NM	None	SD 826160	Typical		" " " "
	119	Harper Clough Quarry	0.6	3.20	None	SD 717316	Typical		Author's
	118	Longworth Valley Exposure	1.64	0.60	None	SD 689157	Late		Author's
3	104	Nan Scar Beck	1	1	None	SE 034333	Late	12-18, though 9.9 at Snail Green(SE 118425) and only 5 in Horsforth waterworks bore Stephen's et al. (1953)	Stephen's et al. (1953)
	110	Kirk Lane Dyeworks	1.5	NM	Lingula mytiloides O.nitida	SE 203410	Late		" " " "
	111	Horsforth Waterworks Bore	2.4	2.7	None	SE 231411	Lingula Band		" " " "
2	102	Sowerby Bridge Railway Cutting	0.30	7.4	None	SE 069235	Late	Generally 12-15m, but 36m at Quarmby Clough Mill Bore	Wray et al. (1930)
	100	Butts Clough	NM	?0.15	NM	SE 045179	Typical		" " " "
	96	Bradley Clough	NM	0	NM	SE 076134	Late		" " " "
	97	Spring grove Mill	NM	NM	NM	SE 098144	Typical		" " " "
	99	Quarmby Clough Mill Bore	0.30	0.60	None	SE 108170	Late		" " " "
	103	Head of Bare Clough	NM	0	NM	SE 018309	Lingula Band		" " " "
	98	Mold Green Bore	NM	NM	NM	SE 158164	R.meta-bilingue		" " " "
1	39	Hawden Clough	0.60	0.90	Plant	?SE 128039	Late & R. meta-bilingue	Varies from 12m in the NW to over 30m in SE. At Mossley where the Hazel Greave Grit (p.) are absent the R.bilingue Late and R.super-bilingue beds are only 12m apart	Bromehead et al. (1933)
	86	Pike Lowe	2.4	0	None	?SK 207977	Typical + meta-bilingue		" " " "
	85	Stream north of Ewden Lodge	NM	0	NM	?SK 235974	Late + meta-bilingue		" " " "
	84	Small field area	NM	0	NM	-	Late		" " " "
	91	Near Mossley	1.8	0	None	?SD 973013	Late		" " " "

Table 6B. Band of R. bilingue, late

Area Number	Base Map Locality Number	Locality	National Grid Reference	Type of R.bilingue	Source of Data
4	117	Deeply Vale (North parts)		R. metabilingue	Wright *et al*. 1927
	114	Tower Clough	SD 905261	Typical	" " " "
3	105	Harden Clough	SE 040334	Late (L)	Stephens *et al*. 1953)
	107	Hewenden Valley	SE 077361	" "	" " " "
	106	Neav Marsh	SE 027354	Late (U)	" " " "
	109	Kirkstall Wood Excavation	SE 065397	" "	" " " "
	108	Lee Moor Borehole	SE 061380		" " " "
2	101	High Lee Clough	SE 050212	Typical	Wray *et al*. (1930)
1	90	Howels Head	?SE 050029	Late	Bromehead *et al* (1933)
	95	Netherly Quarry	SE 045108	Late & R.metabilingue	" " " "
	95	Pule Hill (Eastern slopes)	" "	" "	" " " "
	88	Langsett Moors	?SE 131012	Late	" " " "
	87	Carbin Clough	?SK 170995	Late	" " " "
	92	Holme Moss Area (e.g. Ramsden Clough)	SE 119026	Absent	" " " "
	94	SW of West Nab	SE 063090	Absent	" " " "
	93	Holmforth Area	SE 142078	Absent	" " " "

presumed to be continuous with *R. bilingue* late band (Bromehead *et al*. 1933). Typical exposure of this band is shown in Figure 12 (a,73m level).

The *R. bilingue* late band occur in a composite form in area 3, and the distribution of the components as established by Stephens *et al*. (1953) are shown in Figure 9 .

Discussion

The *R.bilingue* typical band is regarded as a good stratigraphic marker. It is relatively thin, easily recognizable, generally persistent and remarkably widespread. Its absence in the south eastern parts of area 1 is regarded as a local effect because the same band is recorded in the Ashover Boreholes of North Staffordshire (Ramsbottom, *et al*. 1962), in North Wales (Wood, 1936) and in Belgium (Dermanet 1941). It is not clear whether the *R.bilingue* typical band in areas 1, 2, 4, 5 is as amalgamated as in area 3 but has not been positively identified into component horizons, or whether it is genuinely a simple band in these places. If the latter applies, the character of *R. bilingue* typical in these areas 1-5 resembles that in North Staffordshire where *R. bilingue* band shows a considerable variation in the number of fossiliferous horizons developed (Ashton 1974). For instance, while the typical *R. bilingue* band is represented by a single marine unit on the southern margins of the North Staffordshire basin, it is represented by 3 and "at least 2" marine bands in the Upper Churnet Valley and River Dove Section respectively (Ashton 1974).

The band of *R. bilingue* late displays characteristics similar to R. bilingue typical and so is also considered as a good correlation marker. The occurrence of R. bilingue late band in both simple and composite manner as in R. bilingue typical band is interpreted in a similar way as in the case of the latter band. The absence of R. bilingue late in the Holme Moss and Black Hill parts of area 1 is regarded as a local effect which may be palaeotopographically or structurally influenced. The proximity of the top of the second major sandstone unit above R. gracile band to R. superbilingue band in these localities probably suggests that the shale unit in which R. bilingue usually occurs did not develop, in other words a facies controlled effect.

The bands of R. bilingue early and R. metabilingue are not considered good correlation markers mostly because of their restricted distributions.

Like R. gracile bands, the R. bilingue bands are considered to represent periods of high salinity within the Central Pennine basin.

2.1.3. The Reticuloceras Superbilingue Band R2C

The band occurs at the base of the mudstone overlying the third major sandstone unit occurring above the R. gracile band. Genus Gastrioceras makes its first appearance occasionally in this band, but it is not abundant.

R. superbilingue band is widespread, and occurs in all areas (Fig. 10). It is however sporadic in some parts of areas 2 to 5, where the band interpreted by Wray et al.(1930), Stephens et al. (1953), Wright et al. (1927) and Earp et al. (1961) as its lateral equivalent are occupied by Lingula mytiloides and occasionally by

Table 7. Band of R metabilingue

Area Number	Base Map Locality Number	Locality	Thickness of Marine Band (M)	Height of occurrence of Marine Band (M) above R.oil.(L) or Pule Hill Grit (PH)	Type of Fossil in Mudstone below Marine Band	National Grid Reference	Type of Marine Band	Thickness of mudstone between Pule Hill (p.) and Hazel Greave Grit. Other observations	Source of Data
4		Hodge Clough	NM	4.5 (above R.bil.L)	R.bilingue (L)	SD 788194	Metabilingue		Wright et al.(1927)
		Cheesden Lumb Mill	1.5	7.5	Posidoniella sp. Pterinospecten sp.		Metabilingue	Variable but commonly 10-30	" " " "
		Longworth Valley Exposure	NM	2 (above R.bil.L)	R.bilingue late	SD 689157	Metabilingue		" " " "
2		Mold Green Bore	0.60	10.2 (above PH)	None	SE 158164	Metabilingue	Generally 12-15, but 37 at Mold Green Bore	Wray et al. (1930)
1		Near Mossley	4.5	0.30 (above R.bil.L)	R.bilingue late	?SD 973013	Metabilingue		Bromehead et al. (1933)

Table 8A. Band of R. superbilingue

Area Number	Base Map Locality Number	Locality	Thickness of Marine Band (M)	Height of occurrence of Marine Band above Hazel Greave Grit (p.)	Type of Fossil in mudstone below marine band	National Grid Reference	Type of Marine Band	Thickness (M) of mudstone between Hazel Greave Grit (p.) and Huddersfield White Rock in the area. Other observations.	Source of Data
5	168	Trawden Brook	0.45	1.5	NM	SD 920372	R.sup	Usually about 9m or less	Earp et al. (1961)
	169	Monkroyd Beck	0.6	NM	NM		Lingula		" " " "
3	151	Near Fosse Intake	0.15	0.15	NM	SD 983354	R.sup	Commonly 9-15m	Stephens et al. (1953)
	152	Blue Scar Beck	NM	0.90	NM	SE 000399	R.sup		" " " "
	150	Nab Water Beck Bank	NM	0	None	SE 028326	Lingula		" " " "
	153	Small Wood SE of Laes Moor	NM	3	NM	SE 063377	Lingula		" " " "
	155	Baildon Combing Co. Boring	3	0.5	None	SE 154382	R.sup		" " " "
	154	Saltaire Mills Boring	NM	0	NM	SE 141380	Lingula		" " " "
	156	Bingley Brick Pit	0.42	0.10	Plant	SE 112412	Lingula		" " " "
	157	NE of Prospect House	0.75	0.75	NM	SE 109435	Lingula		" " " "
	158	Horsforth Waterworks Bore	NM	0.88	NM	SE 231411	R.sup		" " " "
2	144	Head of Butt's Clough	NM	4	Lingula	SE 045179	R.sup	30 or more in the south, but commonly 9m in the north	Wray et al. (1930)
	146	Bottoms Farm	0.6	4	Lingula	SE 062193	R.sup		" " " "
	147	Black Brook at Bowers Mill	0.6	4.5	Lingula	SE 070203	G.?Sigma R.sup		" " " "
	138	Heath House Clough	NM	3	Fish Remains Lingula	SE 091157	G.?Sigma R.sup		" " " "
1	136	Royd Edge	NM	NM	NM	SE 089095	R.sup	Commonly 21-24m	Bromehead et al. (1933)
	128	Ramsden Clough	0.3	3	Lingula	SE 119036	R.sup		Author
	130	Hey Clough (near its top)	0.3	5	Lingula	SE 081052	G.?Sigma R.sup		Bromehead et al. (1933)
	132	Black Dike	0.15	NM	NM	SE 080055	G.Cancel-atum R.sup		" " " "
	120	Shaw Clough	0.9	2.5	NM	SE 219984	R.sup		" " " "
	134	Slackcote	NM	1.8	Lingula	SD 973093	G.?Sigma R.sup		" " " "
	129	Crowden Little Brook	4.5	NM	NM	SE 078040	R.sup(U)		" " " "
	129	Crowden Little Brook	4.5	NM	NM	SE 078040	R.sup(M)		" " " "
	129	Crowden Little Brook	4.5	NM	NM	SE 078040	R.sup(L)		" " " "
	126	South of Greenfield	5.6	NM	NM	? -	R.sup + G.?Sigma R.sup		" " " "

Table 8b. Band of R. Superbilingue

Area Number	Base Map Locality Number	Locality	National Grid Reference	Type of Band	Source of Data
5	167	Will Moor Clough	SD 919363	R. superbilingue	Earp et al. (1961)
4	165	Longworth Valley Exposure	SD 689157	R. superbilingue	Wright et al. (1927)
	163	Deeply Vale		R. superbilingue	" " " "
	164	Head of Hodge Clough	SD 788194	G. ?sigma	" " " "
	164	Head of Hodge Clough	SD 788194	R. superbilingue	" " " "
	166	Royshaw Brickworks	SD 687297	R. superbilingue	" " " "
	159	Gorpley Clough	SD 913232	G. sigma	" " " "
	159	Gorpley Clough	SD 913232	R. superbilingue	" " " "
	162	Green Clough	SD 900264	G. ?sigma	" " " "
	162	Green Clough	SD 900264	Lingula	" " " "
	160	Tower Clough	SD 905255	G. ?sigma	" " " "
	161	Pauls Clough	SD 910274	Lingula	" " " "
2	139	Mold Green Bore	SE 158164	Absent	Wray et al. (1930)
	148	Head of Load Clough	SE 051256	R. superbilingue	" " " "
	149	Cat i th'Well Clough	SE 045286	Lingula mytiloides	" " " "
	141	Red Lane Dike	SE 068165	Gastrioceras sp.	" " " "
	141	" " "	108170	R. superbilingue	" " " "
	140	Quarmby Clough Mill Bore	SE 108170	Absent	" " " "
	145	Bottomley Clough	SE 065195	Marine band	" " " "
	142	Gosport Clough	SE 084182	R. superbilingue (in 3 horizons)	" " " "
	143	Clough House Mill	SE	R. superbilingue	" " " "
1	137	Bradley Clough	SE 077120	R. superbilingue	Bromehead et al. (1933)
	135	Banister edge quarry	SE 087093	R. superbilingue	" " " "
	131	Rake Dike	SE 094048	R. superbilingue	" " " "
	127	Heyden Brook	SE 094029	R. superbilingue	" " " "
	125	Dearden Clough	SE 140018	R. superbilingue	" " " "
	124	Reservoir East of Dunford Bridge	SE 158015	R. superbilingue	" " " "
		Dump, near foot of Long Grain	SE 168023	R. superbilingue	" " " "
	121	Thickwood Brook	SE 208988	R. superbilingue	" " " "
	133	NW part of Delph	?SD 973093	R. superbilingue	" " " "
	122	Little Don (upper part)	? 190995	R. superbilingue	" " " "
	123	Long Grain	SE 168023	G. ?sigma	" " " "

Gastrioceras _sigma_ (Fig. 10).

Several authors (Bromehead _et_ _al_. 1933; Wray _et_ _al_. 1930; Wright _et_ _al_. 1927) contend that the _R_. _superbilingue_ band occurs in a composite manner as shown in Figure 10, and that impressions of _Lingula_ often characterise the commonly 3m thick mudstone unit occurring between its base and the top of the third major sandstone unit above the _R_. _gracile_ band (Table 8A).

Discussion

As in the case of _R_. _bilingue_ typical band, because the _R_. _superbilingue_ band occurs all over the study area, is commonly thin (Table 9) it is regarded as a valuable correlation marker.

However, the dying out of this band northwards and its change to _Lingula_ _mytiloides_ may be indicative of a less marine influence northward. This change may be due to either the proximity of the northern areas to terrigenous sources or to the northern areas being shallow or even to the northern area being less conducive to colonization by _R_. _superbilingue_ goniatites.

Also as in the bands of the typical and late variants of _R_. _bilingue_ and also _R_. _gracile_, the band of _R_. _superbilingue_ shows considerable variation in thickness and in the number of goniatite horizons developed within it in the study area (Figs. 6, 8 to 10, Tables 3A, 5A to 8B). However, in contrast to the case of the bands of other species, the composite bands of _R_. _superbilingue_ are more pronounced in the southern areas than in the northern.

2.2. CHRONO- & LITHO-STRATIGRAPHY

2.2.1. TERMINOLOGY AND INTRODUCTION

Definition of the nomenclature of the rock units, adopted in this study is necessary for the discussion of chrono- and litho-stratigraphy. The multifarious rock-stratigraphic names, with localized derivation and significance, adopted by previous workers (Table 1) in this area have led to confusion in the past.

These various rock-stratigraphic names have been listed again in the middle column of Figure 11and the single geographic name adopted here for each group of equivalent rocks is shown in the right hand column. The chrono-stratigraphic interval in which they occur is specified in the left hand column. For instance, all the lithofacies occurring between the bases of the bands of *R. gracile* and *R. bilingue* typically belong to the Scotland Flags Time-Stratigraphic Interval. The latter will be referred to as Scotland Flags Interval. The main sandstone dominated units occurring at the upper parts of this interval and which had hitherto been known variously as Scotland Flags, Readycon Dean Series and East Carlton Grit will be referred to as the Scotland Flags. The mudstone dominated unit which usually occurs below the Scotland Flags will be called Scotland Flags Mudstone. Rarely, a mudstone unit also occurs between the top of Scotland Flags and the base of *R. bilingue* typical band. In such cases the mudstone will be referred to as Upper Scotland Flags Mudstone. This nomenclatural procedure also applies to the overlying Pule Hill and Hazel Greave Intervals (Fig.10).

The areal order of discussion adopted in section 2.1. will again apply in the discussions of this section. In each area, the broad litho-stratigraphic units are described in stratigraphic order in relationship to their larger time stratigraphic interval. The lateral and vertical relationships of these units within each area are discussed with reference to the stratigraphic section constructed for the area. Similarly, the general thickness variation of each interval and its corresponding sandstone unit within each area is discussed with reference to the general thickness distribution plot made for each area.

The correlation within each area is fairly easy and good due to the common occurrence of marker goniatite bands. Vertical and lateral variations between the units are generally recognizable. Inter-area correlation is also possible, particularly where all the marker goniatite bands are present.

2.2.2. THE SCOTLAND FLAGS INTERVAL

The boundaries of this interval, together with their widespread nature have been discussed in sections 2.1.1. and 2.1.2.

Area 1. In this area the complete succession of this interval is exposed only in stream sections. For instance, the four sections plotted in Fig.12 , which are the best exposed sections, are all stream sections. The correlated lateral extent of this interval is 15.5km, stretching from Ramsden Clough (SE 121038) in the southeast to Readycon Dean Clough (SD 993127) in the northwest.

Table 9. THICKNESS OF SCOTLAND FLAGS INTERVAL

Location	Area	Grid Reference	Thick-ness(m)	Section Type	on cross-section	Source/Remarks
Ramsden Clough	1	SE 121038	43	Surface	Yes	Own work
Rake Dike	"	SE 100052	42	"	"	" "
Wessenden Reservoir	"	SE 062087	?52	"	"	" " (fault in section)
Readycon Dean	"	SD 993127	27	"	"	" "
Woodhead Station	"	SE 100000	60	Subsurface	No	Bromehead et al. (1933)
Red Lane Dike	2	SE 062175	43	Surface	Yes	Own work
Foster Clough Quarries	"	SE 020276	?54	"	No	" " & Wray et al. (1930)
Scotland Quarries	"	SE 033268	?54	"	No	" " " " " " "
Colne Road Mills	"	SE 145159	68	Subsurface	Yes	Institute, Geol. Sci., Leeds
Mold Green, Huddersfield	"	SE 158164	70	"	Yes	" " " "
Mill Yard, Bore	"	SE 108157	69	"	No	" " " "
Quarmby Clough, Huddersfield	"	SE 108170	71	"	Yes	" " " "
Blamires Bore	"	SE 140175	68	"	No	" " " "
Shaws Paper Mill	"	SE 068191	62	"	No	" " " "
Greetland Dyeworks	"	SE 082208	-	"	No	" " " " (base not reached)
T. Ramsden Bore	"	SE 093249	-	"	No	" " " " " " "
Bowers Mill Bore 1	"	SE 070203	64	"	Yes	" " " "
" " " 2	"	SE "	63	"	No	" " " "
Baldwin Bore	"	SE 099252	65	"	Yes	" " " "
Park Wood Quarry	3	SE 066407	28	Surface	Yes	Own work
Horsforth Waterworks Bore	"	SE 231411	48	Subsurface	Yes	Stephens et al. (1953)
Rag Clough, Oxenhope	"	SE 014338	36	Surface	No	Own work
Snail Green Bore	"	SE 1184425	30	Subsurface	No	Stephens et al. (1953)
Sunny Bank Farsley	"	SE?215352	26	"	No	" " " "
Kirk Lane	"	SE 203410	54	"	No	" " " "
Fletcher Bank	4	SD 805165	6	Subsurface	Yes	Institute Geol. Sci., Leeds
Gorpley Clough	"	SD 915235	-	Surface	Yes	Own work (not reached)
Owler Clough	"	SD 947196	-	"	Yes	" " " "
Sabden Brook	5	SD 746341	74	Surface	Yes	Own work

*Not in Figs. (A-A to E-Ei)

The 45m thickness at Ramsden Clough is the most reliable maximum thickness encountered in the field, because the thickness at Wessenden is questionable due to the presence of a fault whose exact throw is uncertain. The thickness variation of the interval is shown in Figures 12 and 13 and Table 9. Regionally, the interval diminishes in thickness towards the southeast, west and southwest (Bromehead _et al._ 1933).

Area 2. This area is rich both in stream and quarry exposures and in subsurface sections. The section of the Red Lane Dike (SE 047224) provides a complete vertical section of the interval thereby providing excellent opportunity for the subsurface sections to be correlated with the exposed successions and to be better understood. Numerous other subsurface sections (Figs.2A & 13) containing this interval are not included in the "B-B1" cross section but were also correlated to the surface section, and the thickness of the interval was derived from them for the general thickness plot.

The thickness of the interval ranges from 43-71m, and the general thickness variation shown in Figures 13 & 14 and Table 9 do not appear to have any preferred trend.

Area 3. Comparable to the situation in area 2, the quarry and stream exposures were correlated with and utilized in the full calibration of the logs of several boreholes. Both the Park Wood Quarry (SE 066407) Keighley, and Rag Clough (SE 014338) Oxenhope, provide fairly complete succession of this interval, though the lowermost 8m of the Park Wood section and the middle 14m of the Rag Clough section are covered. The only other detailed and complete section of this interval included in the "C-C1" stratigraphic section (Fig. 15) is from the borehole at Horsforth Waterworks (SE 231411). Other complete borehole sections through this interval at Kirklane Dyeworks (SE 203410), Snail Green (SE 118425) and Sunny Bank Mills, Farsley (SE 215352) were correlated to the surface successions but were not included in the "C-C1" cross-sections. The Ponden Clough (SD 980364) section which belongs to this area is incorporated in the "D-D1" section (Fig. 16) to aid inter-area correlation. The "C-C1" cross-section is oriented generally east-west (inset map Fig. 15). Extending from Branshaw Quarry (SE 931402) in the west to Horsforth borehole in the east, involving a lateral extent of some 24.5km.

The interval thickness ranges from 26-54m and the general thickness variation is shown in Figures 13 & 15 and Table 9.

Areas 4 & 5. Sections through this interval are exposed only at Fletcher Bank Borehole (SD 805165) and Sabden Brook (SD 746341) in areas 4 and 5 respectively.

The thickness of the interval at the borehole is only 6m, while it is 74m at Sabden Brook (Figs. 13 & 17).

2.2.2.1. Scotland Flags Mudstone

Areas 1-5. This is generally a mudstone unit, though in some sections (a, b & c of Fig. 12; b, c, e & f of Fig. 14 ; C of Fig. 17) siltstone and sandstone beds are repeatedly intercalated. Generally only the Scotland Flags mudstone occurs, however, at a of Figure 12; d, e, g of Figure 14 thin Upper Scotland Flags mudstone occurs. The Upper Scotland Flags mudstone exposed at c (Fig. 17) is 30m thick, which is exceptional.

2.2.2.2. Scotland Flags

Area 1: Extensive exposures of Scotland Flags in this area occur in the lower parts of streams and occasionally in quarries. In most cases it is located 20-30m above the top of the Upper Kinderscout Grit. Its base is generally gradational while its upper boundary is commonly sharp.

In area 1, the Scotland Flags, locally known as the Readycon Dean Series (Bromehead _et al._ 1933), consists of an alternating series of thin bedded sandstones and mudstones and occasional interbeds of ganister and fireclay. The common range of bed thickness in this series is 10-20cm, though 1-2cm & 30-50cm thick beds occasionally occur. Although the Readycon Dean Clough is regarded as the type locality (Bromehead _et al._ 1933), an equally good section occurs at Wessenden Reservoir (SE 062087). Southeastwards, the Scotland Flags consist of two mappable leaves; a dominant lower leaf and an upper leaf composed of thick bedded sandstone. The typical exposures of these two leaves occur at Rake Dike (SE 100052) and Ramsden Clough and the contact between them is gradational. The best exposure of both leaves occur at Diggley Quarry (SE 110074) where the lower 14m consists of even bedded sandstone unit. The lower leaf however differs from the typical Readycon Dean Series because of its disproportionately thick (0.6-2.6m) sandstone beds, compared with its thin (0.15-0.23m thick) mudstone interbeds.

Table 10. THICKNESS OF SCOTLAND FLAGS

Location	Area	Grid Reference	Thick-ness(m)	Section Type	on cross-section	Source/ Remarks
Ramsden Clough	1	SE 121038	20	Surface	Yes	Own work
Rake Dike	1	SE 100052	20	"	"	" "
Wessenden Reservoir	1	SE 062087	?13	"	"	" " (fault in section)
Readycon Dean Clough	1	SD 993127	12	"	"	" "
Woodhead Station	1	SE 100000	53	Subsurface	No	Bromehead et al. 1933
Diggley Quarry	1	SE 110074	30	Surface	"	Own work (base not reached)
Red Lane Dike	2	SE 062175	19	Surface	Yes	Own work
Triangle Railway Cutting	2	SE 047224	19	"	No	" " (base not reached)
Foster Clough Quarries	2	SE 020276	19	"	No	" " " " "
Scotland Quarries	2	SE 033268	30	"	No	" " & Wray et al. (1930)
Bare Clough	2	SE 018309	20	"	Yes	" "
Riverside Cemetery Quarry	2	SE 053237	16	"	No	" " (base not reached)
Colne Road Mills	2	SE 145159	24	"	Yes	Institute, Geol. Sci., Leeds
Mold Green, Huddersfield	2	SE 158164	33	Subsurface	Yes	" " " "
Mill Yard Bore	2	SE 108157	24	"	No	" " " "
Quarmby Clough, Huddersfield	2	SE 108170	27	"	Yes	" " " "
Blamires Bore	2	SE 140175	17	"	No	" " " "
Shaws Paper Mill	2	SE 068191	36	"	No	" " " "
Greetland Dyeworks	2	SE 082208	23	"	No	" " " "
T Ramsden Bore	2	SE 093249	25	"	No	" " " "
Bowers Mill Bore 1	2	SE 070203	40	"	Yes	" " " "
" " " 2	2	SE 070203	39	"	No	" " " "
Bald in Bore	2	SE 099252	20	"	Yes	" " " "
Park Wood Quarry	3	SE 066407	8	Surface	Yes	Own work
Horsforth Waterworks Bore	3	SE 231411	36	Subsurface	Yes	Stephens et al. (1953)
Rag Clough, Oxenhope	3	SE 014338	26	Surface	No	Own work
Snail Green	3	SE 118425	6	Subsurface	No	Stephens et al. (1953)
Sunny Bank, Farsley	3	SE?215352	15	"	No	" " " "
Kirk Lane	3	SE 203410	33	"	No	" " " "
Riddlesden Quarry	3	SE 068430	9	Surface	No	Own work (base not reached)
Fletcher Bank	4	SD 805165	0	Subsurface	Yes	Institute, Geol. Sci., Leeds
Sabden Brook	5	SD 746341	26	Surface	Yes	Own work

The exposed Scotland Flags of this area range in thickness from 12m to over 30m (the base of Diggley Quarry which is 30m thick is within Scotland Flags). Their general thickness variation is shown in Figures 12,18 and Table10. In a more regional context, its thickness of 53m at Woodhead tunnel is considered as a local phenomenon. The general tendency is for the Flags to thin away to the east, west southwest and southeast (Bromehead et al. 1933).

Area 2. Several quarries and streams in this area expose the Scotland Flags. They are also encountered in numerous boreholes (Figs. 2A & 18) and commonly occur 17-45m above the Upper Kinderscout Grit.

The Scotland Flags of area 2 exhibits variations in character when traced laterally. At the Scotland Flags Quarry, Midgley (SE 033268) from where the name of this grit was derived (Wray et al. 1930), the basal 19m of the section consists of well bedded sandstone (Plate 1), while the top 11m is made up of interbedded sandstone and mudstone (Plate 2). This quarry is being progressively filled up and presently only the uppermost 11m of the section remains uncovered. At Foster Clough Quarries (SE 020276), the exposed 19m incomplete section resembles that at Scotland Flags Quarry. At the former, the basal 6m consists of a thickly bedded sandstone (Plate 3), while the overlying 13m is made up of interbeds of sandstone and mudstone which are progressively thinner upwards (Plate 4). The 2.5m thick exposure of these Flags exposed at Delf End Quarries (SE 006297) Pecket Well resembles the lower part of the 11m thick top section of Scotland Flags Quarries. However, in this locality a coal streak on an 18cm thick underclay occurs in these flags (Wray _et al._ 1930).

At Bare Clough (SE 018309) and Red Lane Dike sections, the two leaves comprising this unit appear fairly well defined. While the upperleaf is medium- to coarse-grained, poorly-sorted, massive or cross-bedded, the lower leaf is commonly flat bedded, though not characterised by the sandstone-mudstone interbeds of the Scotland Flags at Readycon Dean Clough in area 1.

In places the distinction between the two leaves is made easier by the presence of a prominent scour at the base of the upper leaf (Fig.14) as in Red Lane Dike. Otherwise the contact is commonly gradational as in Bowers Mill. The thickly bedded sandstone sections of the Riverside Cemetry Quarry (SE 053237) Sowerby Bridge and Triangle Railway Cutting (SE 047224) probably belong to the upper leaf.

Thickness variations accompany the lithologic differences. The Scotland Flags range in thickness from 17-40m and Figures 14 & 18 and Table10show the general thickness variation of the area.

Area 3. While both exposures at Park Wood Quarry and Rag Clough are important because they portray the vertical facies relations of the Scotland Flags, the Park Wood exposure is additionally vital due to its considerable lateral extent. The 150m wide exposure shows lateral facies relationships (Fig. 19) excellently.

When traced laterally, the Scotland Flags of area 3 exhibit marked variations both in texture and in thickness. For instance, in Park Wood Quarry it is made up of an 8m thick sequence of thin-thick bedded, medium-grained sandstone and thin beds of mudstone. The sequence is topped by a 30cm thick coal on a 63cm thick seatearth (Plates 5, 6). Coal also occurs on top of Scotland Flags at Snail Green boring (SE 118425; Deans 1934a). At Riddlesden Quarry (SE 068430), just 2km north of Park Wood Quarry, the lower 6.5m which is very thickly and lenticularly bedded lacks mudstone while its 2.2m upper part resembles the Park Wood sequence (Plate 6). The 8m thick exposure at Derry Hill Quarry (SE 166435) Guiseley area, is coarse-grained to pebbly and rich in plant remains. At Rags Clough, the exposed lower part of the Scotland Flags sequence is medium grained and flat bedded (Fig.20). Based on core description, the 36m thick Scotland Flags section encountered at Horsforth Waterworks borehole consists of three major sandstone divisions. The middle sandstone division which is the thickest is topped by a fireclay unit (Stephens et al. 1953).

The thickness range of Scotland Flags in this area is 6-36m and, based on Figures 15 , 18 and Table 10, it appears to thin remarkably westwards.

Areas 4 and 5. Area 4 has no exposure of Scotland Flags and the unit is absent in the Fletcher Bank Borehole which is the only borehole known to penetrate the interval in this area.

In area 5, the Scotland Flats are exposed only in Sabden Brook (SD 746341), where they occur as a 22m thick, well-sorted medium-grained, flat-bedded sandstone 21m above the R. gracile band.

2.2.3. PULE HILL INTERVAL

Area 1. The exposures of the Pule Hill Interval in this area occur in the same streams that provide the sections of the Scotland Flags Interval discussed earlier. The absence of R. bilingue (late) band in the Ramsden and Rake Dike Cloughs sections makes definition of the upper boundary of the Pule Hill Interval difficult at these localities. However, following Bromehead et al. (1933) and consequently regarding the sandstone unit at the depth interval 43-106m at Ramsden Clough as Hazel Greave Grit, the upper boundary of Pule Hill Grit Interval has been put at the base of the Hazel Greave mudstone of the Ramsden and the Rake Dike sections since R. bilingue (late) band occurs at an equivalent horizon in the northwest and southeast parts of this area.

The thickness range of this interval in this area is 30-50m and Figures 12 & 21 together with Table 11 provide the overall thickness variation of the interval.

Table 11. THICKNESS OF PULE HILL INTERVAL

Location	Area	Grid Reference	Thick-ness(m)	Section Type	on cross-section	Source/Remarks
Ramsden Clough	1	SE 121038	46	Surface	Yes	Own work
Rake Dike	"	SE 100052	41	"	Yes	" "
Wessenden Reservoir	"	SE 062087	?50	"	Yes	" " (fault in section)
Readycon Dean Clough	"	SD 993127	49	"	Yes	Bromehead et al. (1933)
Woodhead Station	"	SE 100000	38	Subsurface	No	" " " "
Heyden Road Rock Exposure	"	SE 097035	30	Surface	No	Own work & Bromehead et al. (1933)
Red Lane Dike	2	SE 062175	29	Surface	Yes	Own work
Bare Clough	"	SE 018309	51	Subsurface	Yes	" "
Colne Road Mills	"	SE 145159	43	"	Yes	Institute Geol. Sci., Leeds
Mold Green, Huddersfield	"	SE 158164	43	"	Yes	" " " "
Mill Yard Bore	"	SE 108157	50	"	No	" " " "
Quarmby Clough, Huddersfield	"	SE 108170	37	"	Yes	" " " "
Blamires Bore	"	SE 140175	50	"	No	" " " "
Shaws Paper Mill	"	SE 068191	51	"	No	" " " "
Greetland Dyeworks	"	SE 082288	47	"	No	" " " "
T. Ramsden Bore	"	SE 093249	43	"	No	" " " "
Bowers Mill Bore 1	"	SE 070203	45	"	Yes	" " " " (not reached)
" " " 2	"	SE 070203	-	"	No	" " " "
Baldwin Bore	"	SE 099252	55	"	Yes	" " " "
Park Wood Quarry	3	SE 066407	58	Surface	Yes	Own work
Horsforth Waterworks Bore	"	SE 231411	36	Subsurface	Yes	Stephens et al. (1953)
Rag Clough	"	SE 014338	30	Surface	No	Own work & Stephens et al. (1953)
Snail Green Bore	"	SE 118425	60	Subsurface	No	Stephens et al. (1953)
Sunny Bank Farsley	"	SE?215352	36	"	No	" " " "
Kirk Lane	"	SE 203410	27	"	No	" " " "
Saltaire Mill	"	SE 141380	36	"	No	" " " "
Ponaen Clough	"	SD 980364	79	Surface	No	Own work
Wicking Crag Quarry	"	SE 049374	46	"	Yes	" " (base not reached)
Fletcher Bank	4	SD 805165	328	Surface & Subsurface	Yes	Own work & Institute Geol. Sci., Leeds
Gorpley Clough	"	SD 915235	?88	Surface	Yes	" " (fault in section)
Owler Clough	"	SD 947196	?87	"	Yes	" " (base "Phatomed". See text)
Tower Hill Side	"	SD 906261	?87	"	Yes	" " " " " "
Sabden Clough	5	SD 746341	79	Surface	Yes	Own work

Area 2. While the basal contact is commonly located directly on top of, or a few centimetres above the Scotland Flags in areas 1, 3 and many localities within area 2, it occurs 9m, 8m and 4.8m above the Scotland Flags at Quarmby Clough Mills, Red Lane Dike and Mold Green Bore respectively (Fig. 14). The complete sections of the interval occur in the same exposures and boreholes that provided the Scotland Flags Interval of this area.

The thickness of this interval ranges from 29-55m and Figures 14 & 21 and Table 11 show the overall thickness distribution of this area.

Area 3. Numerous exposures of this interval occur (Figs.15 & 2A), but nowhere within this area is a complete section of the interval exposed. However, the probable horizons of the contacts were calculated for some of the vital sections that show most parts of the interval, following the works of Stephens et al. (1953) and and by "phantom-horizon" correlations, following Weimer's (1966) work. A "phantom-horizon" is an imaginary time-surface to which closely related strata, having only local distribution are referred (Weimer, 1966). Cases in point include the contacts at Ponden Clough (SD 980364, Fig.17), the upper contacts at the Park Wood Quarry (Fig.15), and Rag Clough sections. Five borehole logs whose details were derived from Stephens et al. (1953) were also correlated to these surface sections.

The thickness of this interval in this area ranges from 27m - 60m and possibly to 79m as suggested by the Ponden Clough section. Figures 15 & 21 and Table 11, which portray the general thickness distributions of this area do not show any preferred thickness trend.

Area 4. As in area 3, nowhere in this area is there a complete section through the interval, different parts being exposed in separate localities (Fig. 16). The common problem with many of the localities within the area is the non-exposure of the lower contact of the interval. The horizon picked for this lower contact at the Gorpley Clough section (SD 915235) is based mainly on feature mapping augmented slightly by the works of Wright _et al_. (1927) in the Dulesgate area. However, even though this horizon is regarded as fairly reliable, it may be somewhat questionable due to the presence of a fault here whose exact throw is uncertain. The determination method of the lower contact of the interval at the Tower Hill (SD 906261) and Owler Clough (SD 947196) sections is the same as was adopted in area 3, though in this area the memoir by Wright _et al_. (1927) was used.

The spectacularly high thickness range of 80-328m for the Pule Hill Grit Interval of this area, together with the general thickness distribution shown in Figures 16 & 21 and Table 11 are associated with a marked increase in thickness to the southwest.

Area 5. The exposure of this interval was noticed at only Sabden Brook and Swinden Water (SD 910330; Fig.17). Harper

Clough (SD 717316) and Royshaw Brickworks (SD 684297) sections belong to area 4 but were included in the cross section of this area in order to aid inter-area correlation. The determination method of the upper contact of the interval at Sabden Brook is the same as was adopted in areas 3 and 4, though in area 5 using the work of Earp et al. (1961).

2.2.3.1. Pule Hill Mudstone

Areas 1-5. This is a dominantly mudstone unit. However, at b (Fig. 12), b and f (Fig. 14), e and g (Fig. 16), and f (Fig. 17) frequent intercalations of sandstone units occur. These incursions are most frequent in e and g of Figure 16. Also in the western and eastern parts of areas 3 and 5 respectively ("ABCD" of Fig. 22) an unusual lithofacies locally known as the "Bluestone" occurs some 9m above the presumed base of Pule Hill mudstone. The details of the "Bluestone" is discussed in Chapter 3. At g (Fig. 14) only, the Upper Pule Hill Mudstone Unit occurs.

2.2.3.2. Pule Hill Grit

The Pule Hill Grit is generally coarser than both the Scotland Flags and the Hazel Greave Grit although its texture varies laterally as discussed below.

Area 1. The Pule Hill Grit is extensively exposed in this area both in streams, at quarries and as natural features on hill-sides. The exposures at Pule Hill (SE 032106) and Ramsden Clough are excellent due to the fact that their fine vertical exposures are also laterally extensive. 0.6km of continuous lateral exposure exists at Pule Hill and 1.2km of total lateral section occurs at Ramsden Clough, though this is not as continuous as at Pule Hill, which is the type locality of this Grit. The Pule Hill Grit in area 1 occurs commonly 19-21m above the Scotland Flags.

Traced laterally, the Pule Hill Grit exhibits both lithologic and thickness variations. For instance, in Pule Hill, the 10.5m thick leaf which is exposed consists of very thickly bedded medium-to coarse-grained sandstone (Plate 8), whereas at Wessenden Reservoir Section which is only 3.6km southeast of Pule Hill, the grit consists of two unequal parts. The lower 22m consists of interbeds of thin, flat-bedded, fine to medium-grained sandstone, siltstone and mudstone while the upper 7m is dominantly medium-grained and cross-bedded. At the Rake Dike section, located 5.2km southeast of the Wessenden section, this grit consists of the following two leaves, a 15m thick lower leaf which is medium-grained, well sorted, thin- and flat-bedded and an Upper leaf, 9m thick, which is medium grained, cross bedded and erosive into the underlying leaf. The two parts are repeated in the 26m thick Ramsden Clough Section, but the contact between them there is dominantly gradational but locally sharp. An interesting feature of the bedding planes of the lower leaf is the presence of the trace fossil Olivellites. The uppermost 2m of the Ramsden Clough section consists of interbeds of fine-grained sandstone and mudstone. The two leaves are indistinguishable at the 22m thick Heyden Road Rock Exposure (SE 097035) and the

21m thick Holmbridge Woodhouse Quarry section (SE 128065). However, at the latter, the uppermost 9.5m thick section consists of interbeds of fine-grained sandstone and mudstone whose thickness decreases upwards.

The Pule Hill Grit ranges in thickness from 23-34m. The general thickness variation shown in Figures 12 & 22 and Table 12 indicate a probably southerly thinning trend. However, the available data used in the plot are limited and not enough to substantiate such an apparent trend. On a more regional basis, Bromehead et al. (1933) contend that this grit is traceable to Rivelin near Sheffield. They also regarded the Pule Hill and Rivelin grits as lateral equivalents, however, Ramsbottom (1966) later correlated the Rivelin Grit with the Huddersfield White Rock instead.

Area 2. The complete succession of this grit is widespread in this area, both in streams, quarries and borehole sections. The grit is separated from the base of its interval commonly by some 15-35m, and 5m at the Red Lane Dike section.

Constancy in character marks this grit when traced laterally, and it appears that its division into two leaves is general. In the Bare Clough section, the two leaves are distinguishable both on textural and structural grounds. The 11m thick basal part consists essentially of interbeds of thin flat-bedded siltstone and sandstone whose bedding planes are covered with trace fossil Olivellites (Plate 9). Occasional trough based interbeds occur

(Plate 10), and the leaf is topped by a seatearth. The 17m thick upper leaf, which is separated from the lower leaf by a 5m thick mudstone unit, is coarse to very coarse-grained, very poorly sorted and massive (Fig. 14). This upper leaf contains a 1m thick mudstone interbed 10m from its base. If the lower leaf is present in the Kebroyd area near Sowerby Bridge, it is not exposed in the 15m thick Kebroyd Quarry (SE 040210). This quarry section consists of medium-grained to very coarse-grained, thickly bedded sandstone. At Ripponden, the base of the 21m thick Hanging Stone Quarry (SE 044200) section is within the 0.6m thick lower leaf which is separated from the overlying 20m thick, medium to coarse-grained thickly bedded sandstone upper leaf by a 0.2m thick mudstone. The same two leaves occur at Red Lane Dike section, and even though the intervening mudstone is lacking, the erosional base of the upper leaf helps to differentiate the two. The division of the Pule Hill Grit of this area into 2 parts by a mudstone unit rich in Lingula, Orbiculoidea, Naticopsis and Nucula acqualis had been reported by Wray et al. (1930). The Pule Hill Grit of the subsurface sections of this area was not divided into their leaves because the intervening mudstone unit was not reported.

The common range in thickness of this grit in this area is 15-36m, and its 4m thickness at Colne Road Mill Bore (SE 145159) is exceptional. The overall thickness variation shown in Figures 14 & 22 & Table 12 shows no preferred thickness trend.

Table 12. THICKNESS OF PULE HILL GRIT

Location	Area	Grid Reference	Thick-ness(m)	Section Type	on cross-section	Source/Remarks
Ramsden Clough	1	SE 121038	26	Surface	Yes	Own work
Rake Dike	"	SE 100052	23	"	Yes	" "
Wessenden Reservoir	"	SE 062087	29	"	Yes	" "
Readycon Dean Clough	"	SD 993127	34	"	Yes	Bromenead et al. (1933)
Woodhouse Station	"	SE 1000000	26	Subsurface	No	' " " "
Heyden Road Rock Exposure	"	SE 097035	21	Surface	No	Own work (base not reached)
Holmbridge Woodhouse	"	SE 128065	12	"	No	" " " " "
Red Lane Dike	2	SE 062175	22	Surface	Yes	Own work
Bare Clough	"	SE 018309	33	"	Yes	" "
Kebroyd Quarry	"	SE 040210	15	"	No	" " (base not reached)
Hanging Stone Quarry	"	SE 044200	20	"	No	" " " " "
Colne Road Mills	"	SE 145159	4	Subsurface	Yes	Institute Geol. Sci., Leeds
Mold Green Huddersfield	"	SE 158164	15	"	Yes	" " " "
Mill Yard Bore	"	SE 108157	18	"	No	" " " "
Quarmby Clough Huddersfield	"	SE 108170	21	"	Yes	" " " "
Blamires Bore	"	SE 140175	30	"	No	" " " "
Shaws Paper Mill	"	SE 068191	23	"	No	" " " "
Greetland Dyeworks	"	SE 082208	36	"	No	" " " "
T. Ramsden Bore	"	SE 093249	17	"	No	" " " "
Bowers Mill Bore 1	"	SE 070203	19	"	Yes	" " " "
" " " 2	"	SE 070203	-	"	No	" " " "(not reached)
Baldwin Bore	"	SE 099252	24	"	Yes	" " " "
Park Wood Quarry	3	SE 066407	36	Surface	Yes	Own work
Horsforth Waterworks Bore	"	SE 231411	23	Subsurface	Yes	Stephens et al. (1953)
Rag Clough	"	SE 014338	18	Surface	No	Own work & Stephens et al. (1953)
Snail Green Bore	"	SE 118425	24	Subsurface	No	Stephens et al. (1953)
Sunny Bank Farsley	"	SE?215352	18	"	No	" " " "
Kirk Lane	"	SE 203410	2	"	No	" " " "
Saltaire Mill	"	SE 141380	30	"	No	" " " "
Ponden Clough	"	SD 980364	56	Surface	Yes	Own work
Wicking Crag Quarry	"	SE 049374	26	"	Yes	" "
Syke Head Quarry	"	SE 040394	15	"	No	" " (base not reached)
Woodhouse Quarry	"	SE 062397	19	"	Yes	" " " " "
Brandshaw Quarry	"	SE 031402	27	"	No	" " " " "
Braithwaite Quarry	"	SE 040418	14	"	No	" " " " "
Fletcher Bank	4	SD 805165	152	Surface & Subsurface	Yes	Own work & Institute Geol. Sci., Leeds
Gorpley Clough	"	SD 915235	54	Surface	Yes	" "
Owler Clough	"	SD 947196	60	"	Yes	" "
Tower Hill Side	"	SD (o6261	?50	"	Yes	" " (base "Phatomed". See text)
Readyshaw Scout	"	SD 942198	30	"	No	" " " " " "
Sabden Brook	5	SD 746341	60	Surface	Yes	Own work
Swinden Waters	"	SD 910330	3	"	Yes	" "
Cowloughton Clough	"	SD 965414	60	"	Yes	" "

Area 3. Most of the exposures in this area occur in quarries and occasionally in streams (Fig. 15), but in spite of the high density of these surface exposures, this area is regarded as poorly exposed, - all the known exposures are restricted to the west. However, the numerous boreholes in the central and eastern parts provide the additional necessary information. The quarry exposures of Branshaw (SE 031402), Braithwaite (SE 040418), Woodhouse (SE 062397), Wicking Crag (SE 049374) are vital because of their large lateral extents, and the Braithwaite quarry which is still operational exposes three dimensional faces locally. In area 3, the Pule Hill Grit occurs commonly 10-25m above the Scotland Flags.

The Pule Hill Grit of area 3, consists of two beds of a fairly constant character. These two beds are commonly separated by a fossiliferous mudstone equivalent to the one at this horizon in area 2 (Stephens *et al*. 1953, Wray *et al*. 1930). A typical locality of the Pule Hill Grit in Area 3 where these two leaves occur together with the intervening fossiliferous mudstone is the Woodhouse Quarry. The present floor of the Quarry is within the lower leaf whose presently exposed thickness is 11m, and which is dominantly medium-grained, well-sorted, cross-stratified and separated from the 6m thick coarse-grained, poorly sorted sandstone by a 2m thick mudstone rich in *Lingula mytiloides* (Stephen *et al*. 1953). Other good exposures of these two leaves together with their intervening fossiliferous mudstone occur at Wicking Crag and Branshaw Quarries (Fig.15), and these two leaves are lithologically similar to those of Woodhouse Quarry. In the

14m, 7m, 18m thick sections of the quarries occurring respectively at Braithwaite (SE 040418), Tarn House Woodhouse (SE 036424),and Baily Park (SE 01340), it appears that only the upper leaf is exposed, whereas the lower division alone is exposed at the 15m thick Syke Head Quarry (SE 040394), and 7m thick Roadside Woodhouse section (SE 024415). The Ponden Clough section differs from the other sections in that it has three distinct sandstone leaves. Its lowermost 7m thick division which is medium grained and topped by coal occurs some 28m above the presumed horizon of *R. bilingue* typical band. A 6m thick mudstone unit separates this lowest leaf from the 25m thick thin-bedded, *Olivellites*-rich, middle leaf which in turn is separated from the uppermost 8m thick leaf by an 8m thick sandy mudstone unit (Fig. 17). The uppermost leaf is coarse-grained to pebbly with a prominent scour base marked by lag concentrates and plant remains.

The common thickness range of Pule Hill Grit in area 3 is 18-40m. The 2m thickness of Pule Hill Grit at Kirk Lane section is exceptionally low and may be a local effect, as is suggested by the general thickness variation shown in Figures 15 & 22 and Table 12.

Area 4. Sections of Pule Hill Grit are extensively exposed in the eastern parts of area 4 (Fig. 16) and at Fletcher Bank Quarry, Ramsbottom. The latter is a working quarry and exposes over 800m length a continuous section of Pule Hill Grit in an excellent 60m thick cliff-face with local three-dimensional views. A short section of the top part of the grit occurs also at Harper Clough Quarry (SD 717316), Blackburn. Pule Hill Grit occurs 20-35m above the Scotland Flags in the eastern parts of area 4 and 180m above the top of the Scotland Flags Interval at Fletcher Bank section.

Laterally, the Pule Hill Grit exhibits a fairly consistent character. For instance in the Rossendale sub-area (Fig.16), the Pule Hill Grit consists of the following three major sandstone leaves; a lowermost thin-, flat-bedded medium-grained unit, a middle thickly bedded, coarse-grained and poorly sorted leaf and an uppermost division which is commonly medium-grained but also coarser-grained. The uppermost leaf, which in area 4 is popularly known as the Helmshore Grit, is separated from the middle leaf by a fossiliferous mudstone (Wright, et al. 1927) which is commonly 6-7m thick. This mudstone yielded Naiadites? and Spirorbis? in the Gin Hall Bore-hole, Bury and in the Bolton Waterworks borehole, Belmont (Wright et al., 1927). The basal 1m of the Fletcher Bank Quarry provides the only known exposure of the lowermost major leaf in Rossendale area, though several exposures at the eastern part of area 4 provide better exposures of it. Fletcher Bank Quarry provides also the typical section for the middle major leaf in Rossendale sub-area. Buckden Clough (SD 789188) section is vital because it shows good exposures of the middle and uppermost leaves, though the gap between its depth levels 55m and 63m (Fig. 16) makes it difficult to pick the true boundary between its middle major leaf and the mudstone underlying the uppermost major leaf. The best known exposure of the Helmshore Grit occurs at the 14m thick section (Fig.23) of the Chatterton Wood Outcrop (SD 795189). Other good exposures of the Helmshore Grit in the Rossendale sub-area occur at Irwell Bank Exposures numbers 1, 2, 3 at SD 789195, SD 788195, SD 789192 respectively and at Hodge Clough (SD 788193).

In the eastern part of area 4, Gorpley Clough (SD 915235) exposes a typical section for the three leaves of the Pule Hill Grit. In this Clough section, the lowermost major leaf which is rich in trace fossil Olivellites is separated from the middle leaf by a 3m thick mudstone. This intervening mudstone is regarded as the lateral equivalent of the Lingula-rich mudstone unit of areas 2 and 3, based on stratigraphic position, lithological similarity and the stratigraphical location of Olivellites, which appears to occur at the same stratigraphic horizon within these areas. The 3m thick uppermost leaf (Helmshore Grit) is separated from the middle leaf by a 6m thick mudstone already mentioned as fossiliferous around Bury, though these fossils may not have extended into the Gorpley area since they are probably absent at Cliviger and Blackburn areas (Wright et al. 1927). It must be emphasised that this mudstone is stratigraphically higher than the Lingula-rich mudstone band of areas 2 and 3 and not its lateral equivalent as was implied by Bromehead et al. (1933) and Stephens et al. (1953). Exposures of the middle and uppermost leaves occur at Tower Hill Side, though the uppermost leaf is very thin (Fig. 16). In the summit sub-area, Warland Wood Quarries (SD 948202) show good exposures of the middle and the uppermost leaves (Fig.24). Good exposures of the lowermost and middle-leaves also in the summit sub-areas, occur at Owler Clough (SD 947196, Fig.16) and Readyshore Scout (SD 942198).

Laterally, a remarkable variability characterises the thickness of Pule Hill Grit in area 4. Its thickness range in this area which is 50-152m, together with the general thickness variation shown in Figures 16 & 22 and Table 12 indicates a southwestwards thickening tendency.

Area 5. This area is generally poor in exposures of the Marsdenian sediments. However, the exposures of the Pule Hill Grit dominate those of Scotland Flags and Hazel Greave Grit. Based on the Sabden Brook succession which is the only section that penetrates the Scotland Flags and *R. bilingue* bands, the Pule Hill Grit occurs 34m above the Scotland Flags or 4m above the *R. bilingue* typical band.

Marked lateral variability both in lithology and thickness characterise this grit. For instance, at Sabden Brook section, it consists of two distinct leaves; a 23m thick lower leaf and a 16m upper leaf. Although only 36m of the Pule Hill Grit are exposed in Sabden Brook, Earp *et al.* (1961) contend that 60m is the average thickness of the Pule Hill Grit in the southwest portion of area 5. Because feature mapping in this area appears to verify this contention, it is felt that the uppermost 20-27m of this grit in Sabden Brook is covered by drift. At the Swinden water exposure (SD 910330) only a 3m thick sandstone unit constitutes the Pule Hill Grit, but at Cowloughton Clough (SD 965414) the unit is composed of 4 leaves (Fig. 17). The Cowloughton succession resembles the Ponden Clough succession, except for the 4th leaf of Cowloughton which is absent in Ponden. At Laneshaw River exposure (SD 955405), which is only 1.3km southwest of Cowloughton, only two sandstone leaves occur.

The Pule Hill Grit of area 5 ranges in thickness from 3-60m and as shown by Figures 17&22 and Table 12 , it appears that there is a thinning of the grit in a southeastwards direction. Such a thinning was also reported by Earp et al. (1961).

2.2.4. HAZEL GREAVE INTERVAL

Area 1. Exposures of this interval occur at Ramsden Clough, Rake Dike, and Laggin Platt Quarry (SE 087093) West Nab. Sections at Readycon Dean and Wessenden Clough in Fig. 14 are derived from Bromehead et al. (1933).

The thicknesses of the interval ranges from 18-39m. This wide range may be misleading, because based on the general thickness variations shown in Figs. 12 & 25 and Table 13 it appears that the

Table 13. THICKNESS OF HAZEL GREAVE INTERVAL

Location	Area	Grid Reference	Thick-ness(m)	Type of Section	Section on cross-section	Source/Remarks
Ramsden Clough	1	SE 121038	21	Surface	Yes	Own work
Rake Dike	"	SE 100052	18	"	Yes	" "
Wessenden Reservoir	"	SE 062087	37	"	Yes	Bromehead et al. (1933)
Readycon Dean Clough	"	SD 993127	39	"	Yes	" " " "
Woodhouse Station	"	SE 100000	33	Subsurface	No	" " " "
Red Lane Dike	2	SE 068167	20	Surface	Yes	Own work
Bare Clough	"	SE 018309	17	"	Yes	" " & Wray et al. 1930)
Colne Road Mills	"	SE 145159	31	Subsurface	Yes	Institute Geol. Sci., Leeds
Mold Green, Huddersfield	"	SE 158164	42	"	Yes	" " " "
Mill Yard Bore	"	SE 108157	37	"	No	" " " "
Quarmby Clough, Huddersfield	"	SE 108170	35	"	Yes	" " " "
Blamires Bore	"	SE 140175	32	"	No	" " " "
Shaws Paper Mill	"	SE 068191	-	"	No	" " " " (not reached)
Greetland Dyeworks	"	SE 082208	38	"	No	" " " "
T. Ramsden Bore	"	SE 093249	38	"	No	" " " "
Bowers Mill, Bore 1	"	SE 070203	34	"	Yes	" " " "
" " " 2	"	SE 070203	-	"	No	" " " " " "
Baldwin Bore	"	SE 099252	34	"	Yes	" " " "
Horsforth Waterworks Bore	3	SE 231411	34	Subsurface	Yes	Stephens et al. (1953)
Rag Clough	"	SE 014338	30	Surface	No	" " " "
Snail Green Bore	"	SE 118425	24	Subsurface	No	" " " "
Sunny Bank, Farsley	"	SE?215352	18	"	No	" " " "
Kirk Lane	"	SE 203410	30	"	No	" " " "
Saltaire Mills	"	SE 141380	24	"	No	" " " "
Wicking Crag	"	SE 049374	30	Surface	Yes	Own work
Bingley Brick Pit	"	SE 112412	18	Subsurface	No	Stephens et al. (1953)
Canal Work Shipley	"	SE	21	"	No	" " " "
Fletcher Bank	4	SD 805165	31	Surface	Yes	Wright et al. (1927)
Gorpley	"	SD 915235	16	"	Yes	Own work
Tower Hill Side	"	SD 906261	29	"	Yes	" "
Scout End	"	SD 942189	22	"	Yes	" "
Hodge Clough	"	SD 788194	34	"	Yes	" "
Longworth Valley Helmshore Outcrop	"	SD 689157	?23	"	Yes	" " (top not clearly defined)
Harper Clough Quarry	"	SD 717316	50	"	Yes	" "
Swinden Waters	"	SD 910330	20	Surface	Yes	Own work & Earp et al. (1961)

Table 14. THICKNESS OF HAZEL GREAVE GRIT

Location	Area	Grid Reference	Thick-ness(m)	Section Type	Section on cross-section	Source/Remarks
Ramsden Clough	1	SE 121038	13	Surface	Yes	Own work
Rake Dike	"	SE 100052	6	"	Yes	" "
Wessenden Reservoir	"	SE 062087	11	"	Yes	Bromehead et al. (1933)
Readycon Dean Clough	"	SE 993127	14	"	Yes	" " " "
Woodhead Station	"	SE 1000000	3	Subsurface	No	" " " "
Laggin Platt Quarry	"	SE 087093	3	Surface	No	Own work
Red Lane Dike	2	SE 068167	11	Surface	Yes	Own work
Bare Clough	"	SE 018309	5	"	Yes	" " & Wray et al. (1930)
Colne Road Mills	"	SE 145159	20	Subsurface	Yes	Institute Geol. Sci., Leeds
Mold Green, Huddersfield	"	SE 158164	12	"	Yes	" " " "
Mill Yard Bore	"	SE 108157	19	"	No	" " " "
Quarmby Clough, Huddersfield	"	SE 108170	17	"	Yes	" " " "
Blamires Bore	"	SE 140175	11	"	No	" " " "
Shaws Paper Mill	"	SE 068191	-	"	No	" " " " (not reached
Greetland Dyeworks	"	SE 082208	13	"	No	" " " "
T. Ramsden Bore	"	SE 093249	22	"	No	" " " "
Bowers Mill Bore 1	"	SE 070203	23	"	Yes	" " " " (not reached
" " " 2	"	SE 070203	-	"	No	" " " "
Baldwin Bore	"	SE 099252	22	"	Yes	" " " "
Horsforth Waterworks Bore	3	SE 231411	25	Subsurface	Yes	Stephens et al. (1953)
Rag Clough	"	SE 014338	14	Surface	No	" " " "
Snail Green Bore	"	SE 118425	18	Subsurface	No	" " " "
Sunny Bank, Farsley	"	SE?215352	18	"	No	" " " "
Kirk Lane	"	SE 203410	21	"	No	" " " "
Saltaire Mills	"	SE 141380	15	"	No	" " " "
Wicking Crag	"	SE 049374	6	Surface	Yes	Own work
Esholt Junction Railway Cutting	"	SE 193413	8	"	No	" " (base not reached)
Moor Lane Quarry	"	SE 196428	9	"	No	" " " " "
Carlton Lane Quarry	"	SE 199431	9	"	No	" " " " "
Bracken End Quarry	"	SE 194433	15	"	No	" " " " "
Milner Field Quarry	"	SE 122384	8	"	No	" " " " "
Bingley Brick Pit	"	SE 112412	12	Subsurface	No	Stephens et al. (1953)
Canal Work Shipley	"	SE?160382	17	"	No	" " " "
Fletcher Bank	4	SD 805165	?10	Surface	Yes	Wright et al. (1927; Fig.5, Rossendale Station
Gorpley Clough	"	SD 915235	8	"	Yes	Own work
Tower Hill Side	"	SD 906261	19	"	Yes	" "
Scout End	"	SD 942189	19	"	Yes	" "
Hodge Clough	"	SD 788194	0.8	"	Yes	" "
Longworth Valley Helmshore Outcrop	"	SD 689157	0	"	Yes	" "
Royshaw Brick Work	"	SD 684297	17	Subsurface	Yes	Wright et al. 1927, Fig. 23). Base not reached)
Harper Clough Quarry	"	SD 717316	25	Surface	Yes	Own work
Swinden Waters	5	SD 910330	? 9	Surface	Yes	Own work

interval is comparatively thin only in the Rake Dike to Ramsden Clough sub areas whereas it may be fairly constant in most parts of area 1.

Area 2. The best exposed succession in this area occurs at Red Lane Dike (SE 047224). The exposure at Bare Clough is poor, though the remarkably good contrasting feature differences aid its recognition. The complete succession of the interval occurs at several of the borehole sections.

The thickness range of the interval is 17-42m but as is shown in Figs. 14 & 25 and Table 13 the interval thickness appears throughout the majority of area 2 to show no systematic change.

Area 3. Excepting the Wicking Crag section, nowhere within this area is a complete succession of this interval exposed. However, the probable contacts for the sections used in Figure 15 have been derived from the works of Stephens et al. (1927; see Table 13 for source of Figs.12,14-17) and by "Phantom horizon" correlation as discussed earlier. Also several borehole sections (Figs.2A & 15 from Stephen et al. (1953) provide other complete subsurface successions of this interval.

The thickness range of the interval is 18-30m and as is shown by Figs. 15 & 25 and Table 13 this interval appears fairly constant in thickness.

Area 4. The exposures of this interval are fairly widespread in this area, being distributed in the northwest, southwest, central and particularly eastern parts. They occur in quarries, cloughs, and hill sides where they form prominent scarps and edges which are commonly accessible. Exposures of the complete successions of the interval occur at Gorpley clough, Hodge clough and Longworth Valley Helmshore outcrop (SD 689157). In many other localities (Figs. 2B & 16), most parts of the succession are exposed excepting the upper parts, particularly the upper boundary. However, the probable level of the latter was derived from the works of Wright et al. (1927).

The thickness range of the interval is 16-50m. The general thickness distribution shown in Figures 16 & 25 and Table 13 indicates an interval thickness increase towards the northwest. However, until more thickness data are available for the large area between Blackburn and the Rossendale sub-areas it will not be possible to confirm this trend of thickness increase.

Area 5. Only at Swinden Waters, does exposure of this interval occur in this area. The preserved upper boundary of the interval plotted in Fig. 17 was derived from the works of Earp et al. (1961) and Stephens et al. (1953) and by "phantom horizon" method of correlation.

The Hazel Greave Interval at Swinden Waters is 20m thick.

2.2.4.1. Hazel Greave Mudstone

Areas 1-5. This is essentially a mudstone unit in all areas except in the southwest parts of area 4 where numerous tabular, thin beds of siltstone very rich in iron-oxide, dominate the central to top parts of the unit. These tabular beds occur respectively 18m and 4m above the R. bilingue late bands at Hodge Clough and Longworth Valley Helmshore and also 4m, 1m and 1m above the R. metabilingue band at Hodge Clough, Sunny Bank (SD 780206) and Longworth Valley Helmshore respectively (Fig. 16).

2.2.4.2. Hazel Greave Grit

Area 1. The exposure of this Grit is sporadic. However, it occurs at Rake Dike, Ramsden Clough and Laggin Platt Quarry (SE 087093) West Nab. While it occurs directly on a 23cm thick "Lower Meltham Coal" underlain by a 30cm thick fireclay at Laggin Platt Quarry, it was recorded 23m and 19m respectively above the horizon of R. bilingue late at Readycon Dean Clough and Wessenden Reservoir (Bromehead et al. 1933). Its occurrence 1m above the presumed horizon of R. bilingue late at Ramsden and Rake Dike Sections (Fig. 12) is exceptional.

Traced laterally, it appears to display a constant character being generally fine grained to very fine-grained. For instance, the 5.4m thick Laggin Platt Quarry section is very light grey, very fine-grained, compact, hard,cross-bedded and ganisterised, while at Rake Dike and Buckden Clough it is very fine grained, thinly-bedded and bioturbated.

Its thickness range in area 1 is 6-14m, and based on Figures 12 & 26 and Table 14 it is thinnest at the central parts but appears to increase slightly towards the north. Bromehead et al. (1933) contend that it dies out eastwards and westwards except at Delph (SD?977084) where it is a 9m thick ganister.

Area 2. Exposures of the Grit occur dominantly in quarries but also in streams and the motorway cutting. The 15m thick motorway cutting (SE 060166) is vital because its 325m long continuous section portrays the lateral relationship of the lithosomes within this Grit excellently. The section exposed at the cutting, which is the upper part of the interrupted Hey Lane Clough sequence (SE 062175-SE060166), continues at the location SE 068167 just 0.8km east of it, within the Red Lane Dike (SE 062175-SE068167). This provides additional details for the augmentation and refinement of the cutting's section.

The Clough Road Quarry section (SE 083156) also shows an excellent 12m thick, some 65m wide continuous section. Several boreholes in this area provide additional subsurface information on the Grit. The Hazel Greave Grit occurs commonly 8-15m above the base of the Hazel Greave Interval, though it occurs 27m above this base at Mold Green, Huddersfield (SE 158164).

Based on its succession at Red Lane Dike, the only outcrop that exposes a complete vertical section, the Hazel Greave Grit is made up of two leaves. A 3m thick poor exposure of parts of the upper leaf occurs at Flint Quarry (SE 012211).

The Hazel Greave Grit of area 2 ranges in thickness from 5-23m, and no preferred trend is exhibited by its general thickness distribution as shown in Figures 14 and 26 and Table 14.

Area 3. The only observed complete succession of this grit in this area is at Wicking Crag Quarry where the Grit occurs 13m above the base of the interval.

Traced areally, the Hazel Greave Grit appears fairly uniform in texture and structure. Generally it appears to consist of one major sandstone leaf. The Wicking Crag Quarry, is a recommended type section of this Grit for area 3, because not only is its entire genetic sequence clearly exposed here, but also the accessibility of the entire quarry face, its 200m wide continuous lateral extent and 6m thickness allow detailed lateral and vertical relationships within the Grit to be closely studied. Except for the base of the Grit which is not exposed elsewhere apart from the Wicking Crag Quarry, the following exposures portray good sections of Hazel Greave Grit; Sugden End Quarry (SE 049375) Haworth, Milner Field Quarry (SE 122384) Bingley, Eshalt Junction Railway Cutting (SE 193413) Yeadon and the following quarries at

Guiseley, Bracken End (SE 194433), Carlton Lane (SE 199431) and Moor Lane (SE 196428). Several boreholes made in this area provide subsurface information.

The thickness range of the Grit is 6-25m and its general thickness distribution shown in Figures 15 & 26 and Table 14 suggest a slight increase in thickness towards the east particularly towards the Guiseley sub-area.

Area 4. Exposures of this Grit occurs dominantly in cloughs and quarries but also on hillsides as prominent scarps. The Scout End and Tower Hill "edges" portray excellent 250m and 100m wide exposures respectively. The Hazel Greave Grit of this area occurs commonly 4-14m above the base of the interval, though 32m and 1m were measured at Hodge Clough and Tower Hillside respectively. The Hazel Greave Grit is developed only in the eastern and northern parts of area 4.

When traced laterally, the Hazel Greave Grit is characterised by variability both in texture, geometry and structure. At its type locality, the Hazel Greave Quarries (SD 915240 and SD 913238) near Hazel Greave farmstead (Wright et al. 1927) its 6.5m thick section consists of a leaf of fine-grained sandstone, whereas at Gorpley Clough section which is only 0.6km to the south, although only one leaf occurs also, it is coarse-grained to pebbly. At Tower Hillside, which is 2.4km northwest of the type locality, the Hazel Greave Grit consists of 3 leaves. The comparative sections of this Grit, especially those exposed in the Cornholme sub-area which are contained in Figure 14 of Wright et al. (1927), provide further details of the variability of this Grit, as one to three leaves of the unit are variously exposed. At Scout End Quarry (SD 942189) in the Summit valley sub-area, three leaves of this Grit are excellently exposed, while at Harper Clough in Blackburn two major divisions occur. Wright et al. (1927) contend that the 0.8m thick ganister in the Hodge Clough section represents this Grit and may be equivalent to the coal and fire clay horizon of the eastern and south eastern parts.

The thickness range of the Hazel Greave Grit in area 4 is 0-25m and, based on the general thickness distribution shown in Figures 16 and 26 and Table 14, the Grit appears to decrease in thickness southwestwards. Wright et al. (1927) contend that it thins south eastwards also. Even though this latter trend is not pronounced in Figure 26, its absence at Owler Clough section (Fig. 16) suggests a thinning east of the Scout End section.

Area 5. At the Swinden water exposure, the only known exposure of this Grit in area 5, the Hazel Greave Grit consists of a 9m thick coarse-grained sandstone overlain by a seatearth.

2.2.5. INTER AREA RELATIONSHIPS AND INTERPRETATION

As is apparent in Figures 12, 14, 15, 16 & 17 , there is a similarity between the detailed stratigraphic successions within the five areas. All three intervals appear in each of the five areas, although with varying degrees of completeness, despite the structural differences in the five areas (Fig. 3). It is not surprising that the sections within areas 1-3 show similar successions, bearing in mind that they are all on the eastern flank of the Pennine Anticline, but the similarity in succession between areas 1 to 3 on the one hand and sections within areas 4 and 5 on the other hand is striking.

Because "genetic sequence of strata" is very useful for reconstructing the palaeodepositional topography of a basin (Busch, 1974), an isopach map of the three intervals was made (Fig. 27). This isopach indicates the existence of an underlying irregular topography which is generally structurally lower to the south west. There is also an indication of a steeper topography southwestwards, commencing just to the southwest of Rochdale. (See Table 15 for other vital details of Fig.27).

The degree of the southwest increase in Marsdenian sediment which is also shown by the Fence diagram (Fig.28) is much better appreciated by comparing the Fletcher Bank section in the southwest with such northeast sections like Parkwood Quarry or the Horsforth Waterworks borehole. Such

Table 15. THICKNESS OF MARSDENNIAN STAGE (R2A-B) OF THIS STUDY

Location	Area	Grid Reference	Thick-ness(m)	Section Type	Section on cross-section	Source/Remarks
Ramsden Clough	1	SE 121038	110	Surface	Yes	Own work
Rake Dike	"	SE 100052	102	"	"	" "
Wessenden Reservoir	"	SE 062087	?139	"	"	Own work & Bromehead et al. (1933) /Fault in section/
Readycon Dean	"	SD 993127	115	"	"	Own work & Bromehead et at. (1933)
Woodhouse Station	"	SE 100000	125	Subsurface	No	Bromehead et al. (1933)
Red Lane Dike	2	SE 062175	100	Surface	Yes	Own work
Colne Road Mills	"	SE 145159	143	Subsurface	"	Inst.Geol. Sci., Leeds
Mold Green Huddersfield	"	SE 158164	158	"	"	" " " "
Mill Yard Bore	"	SE 108157	156	"	No	" " " "
Quarmby Clough Huddersfield	"	SE 108170	148	"	Yes	" " " "
Blamires Bore	"	SE 140175	150	"	No	" " " "
Shaws Paper Mill	"	SE 068191	>114	"	"	" " " " (incomplete section)
Greetland Dyeworks	"	SE 082208	>112	"	"	Inst. Geol. Sci.,Leeds (base not reached)
T. Ramsden Bore	"	SE 093249	>112	"	"	" " " " "
Bowers Mill Bore 1	"	SE 070203	143	"	Yes	Inst. Geol. Sci.,Leeds (incomplete)
" " " 2	"	SE 070203	-	"	No	Inst.Geol.Sci., Leeds
Baldwin Bore	"	SE099252	156	"	Yes	" " " "
Park Wood Quarry	3	SE 066407	116	Surface	"	Own work
Horsforth Water-works Bore	"	SE 231411	109	Subsurface	"	Stephens et al.(1953)
Rag Clough	"	SE 014338	99	Surface	No	Own work & Stephens et al. (1953)
Snail Green Bore	"	SE 118425	114	Subsurface	No	Stephens et al.(1953)
Sunny Bank Farsley	"	SE ?215352	96	"	"	" " "
Kirk Lane	"	SE 203410	108	"	"	" " "
Fletcher Bank	4	SD 805165	365	Surface & Subsurface	Yes	Own work & Wright et al. (1927)
Gorpley Clough	"	SD 915235	?142	Surface	"	Own work (fault at basal part)
Owler Clough	"	SD 947196	137	"	"	Own work
Sabden Brook	5	SD 746341	302	"	"	" "

a comparison emphasises the fact that the Fletcher Bank section is more than twice any of these northeast sections.

The Sabden section is also thicker than any of these northeast sections.

It is noteworthy that this increase occurs only within the Pule Hill interval as is briefly discussed below. The Scotland Flags Interval is thinner in the Fletcher Bank section than in any of the other sections plotted in the fence diagram. Also the total absence of the Scotland Flags in the Fletcher Bank sections probably verifies the view that it may not have contributed towards the general increase of the Marsdenian sediments towards the southwest.

The increase in both the Pule Hill Interval and Pule Hill Grit is thought to be mainly due to the high water depth particularly at the Fletcher Bank sub-area but also at other southwest localities during the R2b time. As is further discussed under the section on palaeogeography (p.278) the existence of this deep water at the R2b time is intimately connected with the westward limit of growth of the Kinderscoutian (R1C) delta system (McCabe, 1975). The increase also appears to be associated with areas where thin sandstone beds are significantly present within the Pule Hill mudstone, such as at Fletcher Bank and Gorpley Clough sections. The implication of this association will be clearer after the discussion later of the sedimentological context of the thin sandstone beds.

It is interesting to observe that the 30m thick Upper Scotland Flags mudstone which occurs at Sabden Brook section thins eastwards (Figs.28 & 17).

The distinct sandstone leaves within the Pule Hill Grit, reduces in number commonly from three at the western parts to one or two at the eastern areas (Fig. 28). The uppermost leaf which is best developed at area 4, particularly at the Rossendale sub-area diminishes in thickness eastwards until it probably amalgamates with the underlying middle leaf.

The inferred lateral equivalence of the coarse-grained upper parts of the Pule Hill Grit in most localities (Fig. 28) implies that the upper parts may be sheet like.

The two *Lingula*-rich mudstone units within the Pule Hill Grit appear fairly extensive within areas 4 and 5 (Fig. 28). Also the occurrence of the lower of the two at areas 2 and 3 have been discussed, and its occurrence at the central parts of area 1 and around Meltham, was reported by Bromehead *et al.* (1930). What is not clear is whether this lower one is genuinely widespread. *Lingula*-rich mudstone units - usually suggest periods when marine conditions were approached but were not fully attained (Wright *et al.* 1927).

The Hazel Greave Grit which is fairly sheet like in areas 2 and 5 is sporadically developed in area 1.

CHAPTER 3: LITHOFACIES

3.0. DEFINITION

The term lithofacies is used in this study in a strictly observational sense, to characterise a group of rocks differing from others in their grain size, composition, sedimentary structures, fossils and occasionally their colour and bedding contacts. Trace fossils however are not included in these criteria, rather they have been treated separately (cf. Collinson, 1967; Baines 1977) in order to avoid a proliferation of facies names due both to the multiplicity of trace fossils and to the wide range of lithofacies in which they occur. Although many of the lithofacies are intergradational, the criteria chosen for their definition are easily observable and so should facilitate their recognition. Also the approach adopted in their definition has been to establish only those few bodies of rock that reflect particular processes or particular environments. It must be emphasised however that most facies, based on their internal features are thought only to indicate the processes that operated and most probably have little absolute environmental significance. Many individual facies are thought to have formed in a range of environmental settings and they should not be taken in isolation in inferring environments. Although many of the lithofacies from the Marsdenian succession resemble those described from the R1 Central Pennine succession by Collinson (1967, 1968, 1969, 1970), McCabe (1975) and from the R2 Roaches Grit succession by Jones (1977) efforts were made not to apply their facies classification in the field in order to ensure objectivity. However, wherever similarities occur they have been pointed out.

The description of the individual facies and the interpretation of the process that operated on them during and after their deposition are made below.

3.1. LITHOFACIES 1. UNFOSSILIFEROUS MUDSTONE

3.1.1. Description

This lithofacies embraces a mixture of unfossiliferous clay, fine silt and occasionally scattered mica flakes, the proportion of these components varying from place to place. The field appearance seems to be controlled by the state of weathering because while fresh deposits are commonly light to medium grey in colour a weathered type is usually dark grey or black and displays prominent brownish-grey stains,probably of limonite. At one extreme this lithofacies is homogenous, hard and conchoidally fracturing to lensoid units whose width commonly ranges from 1-4cm and thickness 0.3-0.5cm. At the other extreme, the lithofacies is fissile and the parallel laminae are commonly less than 0.1cm thick, though occasionally up to 0.2cm thick. Yellow,powdery jarosite, the weathering product of disseminated pyrite, frequently smears the weathered parting planes of the fissile types. There is usually no evidence of current activity. Clay nodules, which are mostly light grey or light medium grey or even brown in colour, are common. Some of these, which are concretions with carbonate cement show laminae which are thicker than those of the surrounding unit. All gradations between these two extremes occur. Bioturbation is rare. Body fossils were not seen.

3.1.2. Interpretation

The fine-grained nature of the lithofacies, the general evenness of its fissility and the lack of current structure suggest that this lithofacies accumulated very slowly from suspension in quiet water. While a rapid and constant supply of muddy sediments may give rise to the homogenous variety of this lithofacies, accelerated mud supply (McCabe, 1975) or a horizontal orientation of the mica flakes and carbon fragments may cause lamination, even though high carbon content often gives irregularities in the laminations (Collinson, 1967).

The concretions are regarded as products of localized deposition of mineral matter in the pores of the sediments about a central nucleus, either penecontemporaneously with sedimentation or shortly afterwards. The mineral constituents are often those which play the role of cement in the host rock. McCabe (1975) contends that the parallel nature of the laminae in the concretion may suggest that (a) the concretions formed rapidly (b) the rate of sedimentation was very slow, or (c) the concretions grew at depth where the rate of compaction was slow. Pyrite forms, in sediments rich in organic material, within the top 5m, at the present day, and also both pyrite and carbonate formation can be due to sulphate reducing bacteria metabolising organic matter (McCabe 1975).

The general absence of body and trace fossils in this lithofacies could have been caused by bottom conditions which were inhospitable to animals. A high content of either unoxidized organic matter or finely divided iron sulphides is capable of generating such a hostile environment (Heckel 1972). A high content of either unoxidized organic matter or finely divided iron sulphides could be indicative of a reducing condition, even th ough diagenesis is not ruled out.

3.2. LITHOFACIES 2. FOSSILIFEROUS MUDSTONE

3.2.1. Description

This lithofacies is gradational with lithofacies 1, unfossiliferous mudstone, and lithofacies 4, carbonaceous mudstone, though it may be easily recognised in the field as a sooty or ashy, black mudstone which is darker in colour than lithofacies 1, and sootier than lithofacies 3. The bedding surfaces of its weathered very thin laminae which are commonly less than 0.1cm thick, are usually richly coated with jarosite, limonite or haematite. Beds vary in thickness laterally and have a range in thickness of 0.9-6.5m (Tables 3-8). Several nodular concretions occur and although the range of the common long and short dimensions is 5-10cm, and 2-5cm respectively, long dimensions of 0.15 and 35cm occur. Occasionally several light grey coloured bands, often rich in silica and iron material occur. Morphologically these bands can either be compact and occur as nodules (Plate 11), or elongate (Plate 12) and generally extensive laterally. The elongate types usually do not exceed 1.5cm in thickness and are often 0.5-1cm thick. Petrographically, they consist of angular quartz grains of some 10 to 40μm in a porous matrix composed of light olive grey clay minerals which portray prominent and dominant light brown stains of probably limonite and rare greyish green colours of probably chlorite. These bands are regarded as siliceous ferruginous claystone, based largely on the percentage of the clay sized components (70%) compared to that (30%) of the rest.

The fauna consists mainly of goniatites, pectinid bivalves such as Dunbarella Speciosa, Posidonia oblique, brachiopods such as Orbiculoidea Sp, nautiloids and gastropods. Most of the fauna is adult, though mollusc spat may also occur. The preservation is commonly as flat impressions in mudstones where the fossils generally lie with their long axes parallel or at low angle to bedding. However uncrushed goniatites occur in nodules and at Light Hazzles Quarry (SD 948194) three specimens of R. bilingue late whose common diameter is 1cm is found to be preserved uncrushed in an upright position, that is with its long axis vertical to the bedding. While it is commonly true that Lithofacies 2 is usually limited to the thin but widespread goniatite marine bands discussed in Chapter 2, it is also true that they can occasionally constitute, or occur within, the relatively thick mudstone units separating such goniatite marine bands. Cases in point include sections at Hodge Clough (Fig. 16), Park Wood (Fig. 15), and Colne Road Mills (Fig. 14). The fossiliferous nature of the lower 12m thick part of the Hazel Greave mudstone at Hodge Clough has been discussed, and the common range of the long and short diameters of the nodules containing the diminutive unidentifiable goniatites is 1-2cm and 0.5 - 1cm respectively. Stephens et al. (1953) contend that the 14.5m thick Scotland Flags mudstone at Park Wood contains ?Athyrid. At Colne Road Mill Borehole, depth interval 118-121m of the Pule Hill mudstone (Fig. 14) contains R. bilingue typical, Lingula, gastropod and other cephalapods at its base and large spines (?Hyalostelia) at its top. Similarly, at Horsforth Waterworks borehole, while R. bilingue late, Rhineoderma sp and Lingula mytiloides occur at about the depth level 62m (Fig. 15), and Sanguinolites sp exist at level 67m, Orbiculoidea cf. nitida and R. bilingue late occur at about level 71m (Stephens et al. 1953) implying that the Pule Hill mudstone is virtually wholly occupied by marine fossils.

3.2.2. Interpretation

Lithofacies 2 is thought to have been deposited in quiet conditions, by the accumulation from suspension of fine-grained sediments based on the same factors as obtained in Lithofacies 1.

Whilstits goniatite faunal beds are widely regarded as representing high salinity, marine (Collinson, 1967, McCabe 1975, Baines 1977) or near marine conditions (Jones 1977), it remains to be conclusively proved that any dominant portions of the Pennine basin were fresh-water (Jones 1977) during the R2 times. The fact that marine fossils dominate significant parts, if not all parts, of the Scotland Flags mudstone and the Pule Hill mudstone of Hodge Clough, Park Wood and Colne Road Mill sections suggests that these units may be entirely marine, at least within these localities. Also based on the facts that the marine fossils within the study area are both nektonic such as the goniatites and pectinid bivalves and benthonic such as the brachiopods indicate that the bottom conditions within the study area might have been oxygenated.

No differences can be recognized between the nodular concretions of this lithofacies and those described earlier in Section 3.1. It is therefore suggested that similar processes of formation operated.

3.3. LITHOFACIES 3. "Bluestone"

3.3.1. Description

Lithofacies 3 consists of a hard, compact, silty mudstone whose colour ranges from medium grey to medium bluish grey. "Bluestone" is lithologically distinct from the other mudstone units of this study and is developed exclusively in the western and eastern parts of areas 3 and 5 respectively (Fig. 22) as already discussed in section 2.2.3.1. The siltstone component of the lithofacies is dominantly angular to subangular, poorly sorted and ranges in size from fine to coarse grains, all in a groundmass of clay minerals.

Petrographically, the composition of this lithofacies, as seen in its 0.6m and 1.5m thick exposures in Ponden Clough and Tarnhill (SE 039427) respectively, is commonly 30% quartz silt, 5% muscovite, 5% feldspar and 60% organic-rich clay matrix. Based on observations in thin section, it appears that the sediment is stratified in this parallel laminae, normally 1-2mm thick though up to 4mm, the lamination being generally marked by alternating dark/brown and light layers.

The lithofacies is commonly rich in anchoring spines and spicules of the sponge Hyalostellia smithi (Stephens et al. 1953). Layers of this lithofacies at Ponden Clough are also rich in radiating rays which show distinct bifurcations. Further details of these rays, regarded as trace fossils, will be given in Chapter 5.

3.3.2. Interpretation

The fine-grained nature of this lithofacies, its parallel lamination and the lack of evidence for current activity suggest that "Bluestone" was deposited in quiet water conditions by the accumulation from suspension of fine-grained sediments. The alternations in the bands may reflect pulsations in current strength, water chemistry or sediment supply. The streaks of brown material probably represent the ultimate decomposition product of biotite (Stephens et al., 1953), and the dark colour is thought to be due to carbon content. The environment of deposition was probably marine based on the abundance of the sponges which are marine animals that live in all depths of water (Black 1970). The environment may also have been conducive to other organisms. The radiating rays regarded as trace fossil and discussed in detail in Chapter 5 suggest that bottom dwelling animals may have been present.

3.4. LITHOFACIES 4. CARBONACEOUS MUDSTONE

3.4.1. Description

This lithofacies consists of clay to silt-size mineral particles, and although it is gradational with Lithofacies 1, Unfossiliferous mudstone, and Lithofacies 2, Fossiliferous mudstone, it is still distinguishable by its highly fissile character and high content of organic matter. Its colour ranges from dark grey or black where fresh to dark brown where weathered. The organic material consists dominantly of abundant comminuted plant debris, large stem fragments, leaf impressions and wood. Mica flakes of up to 2mm length occur. Parallel laminae of siltstone up to 1mm thick are encountered occasionally, and in such cases they occur at regular intervals of some 5mm thereby, imparting a stripy appearance to the deposit. Lithofacies 4, occurs commonly directly on top of coal, though it can also be seen directly underlying coal or alone. It portrays a common thickness range of 0.3-1m. Carbonaceous mudstone appear to be devoid of animal fossils.

3.4.2. Interpretation

Carbonaceous mudstone can form when organic accumulations which are exposed to erosion are redistributed or reworked and mixed with flocculated clays (Flores, 1981). Alternatively, it can also form by the widespread incursions of suspended sediments of flood waters into vegetated areas (Flores, 1981). While the black colour can be diagenetic, it can also result from the relatively high content of either unoxidized organic matter or comminuted iron sulphide which could form under reducing conditions (Heckel 1972). Such a harsh condition can be unfavourable to non-pelagic benthonic life. This is due to a depletion in oxygen caused by the action of anaerobic bacteria which causes the decay of organic matter, thereby leading to the production of Hydrogen Sulphide which fouls the substrate (Heckel, 1972).

3.5. LITHOFACIES 5: MUDSTONES AND SILTSTONES

3.5.1. Description

This lithofacies is made up of an indefinite mixture of clay-to silt-sized particles, and lacks sand-sized grains except for large carbonaceous fragments and mica flakes. The lithofacies is gradational with lithofacies 1, Unfossiliferous mudstone, Lithofacies 2, Fossiliferous mudstone, Lithofacies 4, Carbonaceous mudstone and Lithofacies 4, Siltstone. Consequently, its colour shows all gradation from light grey to dark grey, the degree of lightness being dependent on the percentage of its constituent silt. All grades can appear massive, which is its usual appearance where weathered. When it is traced laterally into fresh material the following four inter-gradational sub-lithofacies may be distinguishable (Plate 13); 5a. Parallel Laminated Mudstone and Siltstone, 5b. Homogenous Silty Mudstone, 5c. Mudstone with

Siltstone Laminations, 5d. Mudstone with Siltstone Lenticles. The interlaminae of 5a usually range in thickness from 0.1-1cm. The siltstone laminae of 5c may be even and parallel or sinusoidal and parallel. The parallel siltstone can grade laterally to a lenticular siltstone of subfacies 5d. Such lenticles are commonly 3cm wide and 0.3cm thick and usually "float" in mudstone, though they can be occasionally inter connected both vertically and horizontally. The lenticles may or may not be rippled.

Numerous sand-filled cylindrical burrows destroy the stratification. The details of this trace fossil will be given in Chapter 5 .

3.5.2. Interpretation

The fine-grained nature of the lithofacies suggest that the sediment was deposited in quiet water by the material falling from suspension. The fluctuation in the current or sediment supply is capable of generating both the alternating parallel laminated mudstone and siltstone and also sub-lithofacies 5c Mudstone with Siltstone Laminations. The fluctuations may be controlled by seasonal factors in a similar way to the formation of rhythmites (Reineck & Singh, 1975). The fluctuations may also account for the generation of mudstone with siltstone lenticles. In this case, the siltstone lenticles probably represent small ripples produced by currents in the lower part of the lower flow regime (Simons et al.1965) when the incomplete silt ripples formed on a muddy substratum are preserved as a result of the deposition of the next mud layer (Reineck & Singh 1975). However, intense bioturbation activity can generate homogenous muddy siltstone from the other sub-divisions of Lithofacies 5.

3.6. LITHOFACIES 6. SILTSTONES

3.6.1. Description

Siltstones range in colour from light to medium grey, and in grain size from fine to sandy silt. Siltstones are gradational with Lithofacies 5, Mudstones and Siltstones, from which they are distinguished by their relatively homogenous lighter colour. Siltstones are commonly micaceous, carbonaceous and laminated. Using the terminology of Campbell (1967) the laminations can be even and parallel or sinusoidal and parallel . In both cases the range in thickness of the laminae is usually from 1-2mm. The lithofacies occurs both as thick individual units of up to 1m thick (Plate 15), or as thin interbedded units of 2-10cm thick. Contacts of siltstones with other lithofacies are gradational to sharp. In some localities in the southwest parts of area 4, particularly at Sunny Bank Cutting (SD 780206), Hodge Clough (SD 788194), and the Longworth Valley Exposure (SD 689157), it is tabularly bedded, with sharp boundaries and monotonously alternates with mudstone, altogether presenting a remarkably regular appearance (Plate 16). Tabular beds of 0.2-1cm and 4-10cm thickness ranges are commonly seen. Petrographically, these tabular beds are regarded as micaceous, ferruginous, siltstone because they commonly consist of 50% of angular to subangular quartz silt, 10% muscovite, 5% of iron oxide which is probably limonite, and some 35% of carbon-rich clay mineral matrix.

Plant fragments and sand filled vertical burrows (trace fossils, see Chapter 5) are commonly abundant. Penecontemporaneous deformation structures are also locally abundant (Plate 17).

3.6.2. Interpretation

This lithofacies is thought to have been deposited mainly from suspension. Any current activity would have been weak based on the general absence of cross-stratification, ripples and primary current lineation. The horizontal orientation of the mica flakes and carbon fragments may have also contributed to the generation of the even and parallel laminated siltstone while the migration and simultaneous upward growth of ripples due to the continually available sediment supply (Reineck and Singh 1975) may have largely produced the sinusoidal and parallel laminated siltstone. The discussion of the probable cause of the deformation structures that occur within Lithofacies 6 will be made in Section 4.4. dealing with Interdistributary Complex Lithofacies Association.

3.6.3. Deformational Structures in Siltstones

3.6.3.1. Description

An excellent cliff-face in Longworth valley (SD 689157) exposes a 1-2m thick deformed unit some 1m above the *R. metabilingue* band (Fig. 29), being separated from it by a mudstone unit with thin stripes of siliceous ferruginous claystone. The contact between this mudstone unit and the overlying deformed bed is gradational. The upper contact of the zone of the deformed bed is scoured and truncates the upper parts of some of the anticlines (Fig. 30, Plate 18) and is also overlain by a 12.4m thick interbed of mudstone and thin-bedded tabular siltstone. Followed along the cliff southwards for some 31m, the deformed unit increases in thickness from 80cm at the northeast end of the cliff-face through 120cm in the middle parts to some 200cm at the southwest end. Folds of two sizes hereby referred to as the major and the minor folds occur. A clear recognition of the major folds, whose amplitude ranges from 1-3m and wavelength ranges from 10-50cm (commonly 40cm), can be made in the northeast parts. Here, both limbs of distinct folds occur. The distinction of major folds is increasingly difficult southwards due to the rupture and discontinuity of the limbs of the various major folds caused by thrusting (Fig. 31). Thrusting also brough several limbs of many folds in close contact with one another in many areas of the lower part of the deformed zone consequently wedging the incompetent mudstone in between the siltstone fold limbs (Fig. 31, Plate 19). Minor folds become more prominent southwards as the limbs of the major fold become increasingly twisted into minor folds whose amplitude ranges from 4-30cm (commonly 10-15cm) and wavelength 5-40cm (often 10-20cm). It is assumed that only one siltstone bed, contorted into a series of folds, may be involved in this deformation. This assumption is based principally on the occurrence of a single contorted siltstone bed occupying the entire deformed zone at the northeast parts (Fig. 30, Plates 20, 21). However, the probable participation of more than one bed is not ruled out. The fold limbs are distorted, and do not retain their original thickness all along their length, particularly towards the base of the deformed zone where they tend to thin (Figs. 30, 31; Plates 18, 19).

In terms of the geometry, a high proportion of the major folds are isoclinal to recumbent. Most of the major folds are angular to rounded in profile. The minor folds are tight to isoclinal, rounded to angular.

3.6.3.2. Orientation of the folds

The relevant orientation data, suggested by Woodcock (1976a, 1979), of as many folds as possible were measured in the different parts of the deformed horizon. Where possible for each fold, the following parameters were measured, fold axis direction, axial plane dip direction, amplitude, wavelength, plunge and plunge direction. A reliable measurement of plunge, its direction, axial orientation and direction of closure required good three-dimensional exposure of the folds, a condition which is satisfied to a variable degree in this cliff-face. The style and sense of closure of fold structures were determined wherever possible. Grading, as seen in the thin sections, was used to determine the nature of closure. Such grading was the only internal way-up feature available, and only a limited number of folds portray this relevant evidence of facing direction.

Based on the directional data presented in Figure 32, the fold axes of both the major and minor folds have a mean NW-SE orientation. The dip direction of the axial planes, and also the fold facing direction, of the major folds are respectively northeast and southwest, indicating therefore that the palaeoslope dipped southwestwards (Woodcock 1976a). The plunge is generally low (commonly less than 5^{0}) and was not given much consideration. The inconsistent directions of the axial planes, dip and facing of the minor folds may have occurred because their associated overturned major folds rolled about their hinges in a more fluid state (Woodcock 1976a).

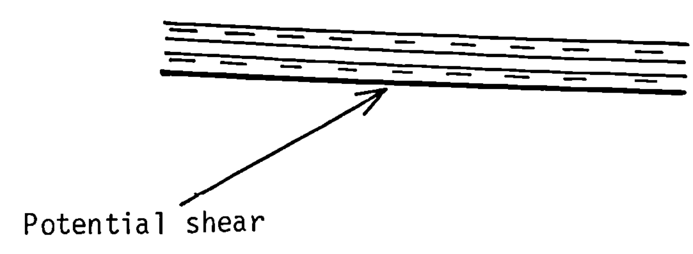
3.6.3.3. Genesis of the Structures

The deformation features similar to the type described here have generally been termed slump structures (Kelling and Williams 1966, Helwig 1970, Woodcock 1976a, 1976b, 1979, Rupke 1978, Johnson 1981). A consideration of the following two factors are deemed relevant to a good understanding of the processes which gave rise to this slumping. First, the time of generation of the features which may be deduced from the inferred physical state of the materials involved in deformation and from the depositional relationship between the deformed zone and the adjacent undeformed beds. Second, the nature and extent of the adjustments, vertical, lateral or a mixture of both which took place to allow the generation of the folded structures within an otherwise concordant sequence. Gross features of the deformed unit, geometry, internal morphology and orientation of the slump structures are some of the vital criteria to the consideration of the two factors.

In the present case, the evidence of truncation at the upper boundary of the unit precludes a tectonic origin (Kelling and Williams 1966, Rupke 1978), and indicates that deformation in the sheet occurred before the deposition of the succeeding overlying unit (Jones 1936). Conversely the heterogeneity of the component deformed lithofacies together with the style of folding indicate that deformation was not penecontemporaneous based on the fact that the deformation took place after the intrabeds of siltstone and sandstone had been entirely laid down but certainly prior to their consolidation. The lateral variation in the deformed zone thickness and the truncation of some of the folds suggest that at least some of the deformation occurred at a free surface, presumably the sediment-water interface. The gross features of the units, particularly the thinning at the basal contact and the inconsistent facing directions of the minor folds are probably evidence for surficial slumping. Many of the folds reveal predominance of recumbent overfolds with subhorizontal axial planes. Such folds are frequently separated by planes of thrusting and at the southwest parts where they tend to pile up, there is an increase in thickness of the unit. These units provide evidence of some degree of lateral transport, involving disruption of the limbs of the major folds. Also the strong unimodal orientation of the major folds' axes reinforced by the consistency in the facing directions are best explainable in the context of lateral translation. The envisaged process involved are demonstrated by means of the annotated sketches below:

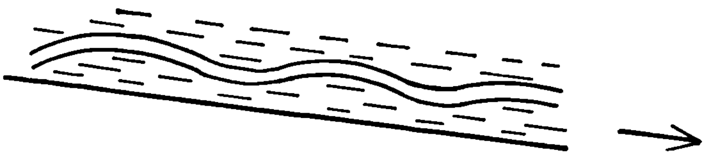
FIG. 33. Processes that generated the slumping in Longworth Valley.

Stage 1: Accumulation of undeformed sediment pile.

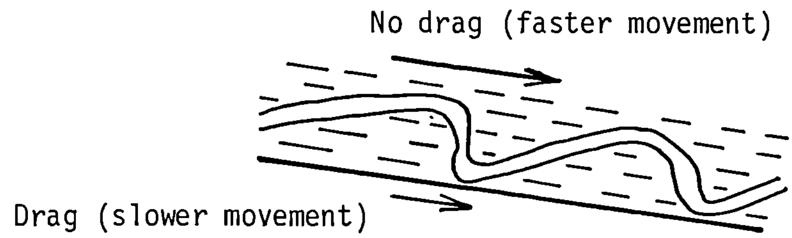


Stage 2: (Flow-fold stage): Due to rapid accumulation of thick undercompated mudstone and siltstone, failure occurs and triggers movement along the shear plane. Minor open folds start developing as the slump mass is translated downslope by the action of gravity,

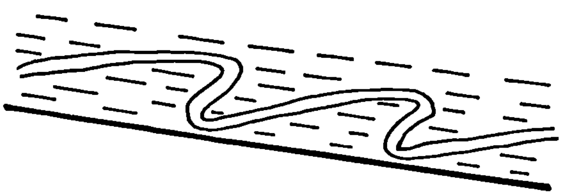
due to the deflection of the major shear stress by each or all of the following five factors proposed by Helwig (1970): rotational movement in the head and toe regions,non uniform frictional stresses causing flow velocity differentials, overriding of bottom irregularities, compressive stress due to deceleration, liquefaction and density foundering causing flow.



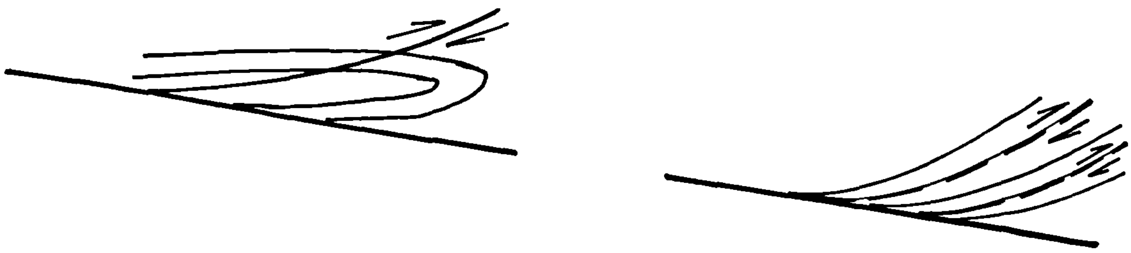
Stage 3: Probably drag along the shear plane contrasted with freer movement at the upper part of the layers generates asymmetry in the folds.



Stage 4: Faster movement accentuates the asymmetry of some of the folds, and they become progressively overturned.



Stage 5: Thrusting ruptures the limbs of these folds, particularly in the southwest parts. In some cases some of the siltstone units pile on top of one another and appear asymptotic at base probably due to drag along the shear plane, and also the increasing influence and imbrication of the thrust faulting.



The extent to which palaeoslope is relevant to slump generation is controversial (Rupke 1978). However recent mapping of sub-bottom structures by the help of continuous seismic profile has shown that slumping does occur on gentle slopes (Lewis 1971), of even one degree (Morgenstern 1967). The overall character of the slump unit, particularly the involved lithofacies indicate that the actual lateral displacement was probably quite small.

3.7. LITHOFACIES 7. RIPPLED SILTY SANDSTONE

3.7.1. Description

Rippled silty sandstone embraces a broad range of fine- to medium-grained sandstones of variable siltstone and mudstone content. Lithofacies 7 resembles Sublithofacies 5c and 5d, Mudstone with Siltstone Laminations and Mudstone with Siltstone Lenticles, and is gradational both into them and with Lithofacies 6, Siltstone, differing from them essentially on grain size. Lithofacies 7 is also gradational into Lithofacies 8, Trough Cross Laminated Sandstone, the main difference being the scarcity or absence of muddy or silty interlaminae. The colour of Lithofacies 7 is dominantly light grey though it also may have variably thick bands of dark grey due to the mudstone components. The sandstone bedding can occur both as isolated or connected lenticles (Plate 22), as climbing ripples (Plate 23), as symmetrical ripples (Plate 24), but dominantly as Ripple Trough Cross Laminated cosets 1-5cm thick (Plate 22). This 5cm upper thickness limit was chosen for convenience, as it is the smallest thickness that can be easily plotted on a vertical log. All ripple trough cross laminated cosets thicker than 5cm are assigned to Facies 8, Trough Cross Laminated Sandstone. While the sandstone lenses can be discontinuous and isolated both in vertical and horizontal directions, the connection of the sandstone lenticles can also occur in both directions, producing connected horizontal lenses of commonly 15-30cm length, and vertically stacked lenticles of commonly 3-4cm thick. At one extreme in Lithofacies 7, the sandstone lenticles "float" in the siltstone or mudstone layer (Plate 25), while at the other extreme the only siltstone or mudstone lamination bands occur mostly as partings between the cosets of ripple trough cross stratified sandstone (Plate 26). All gradations between these two extremes occur. Most lenticles are fairly biconvex in vertical section and lie with their plane of maximum elongation parallel to the bedding, but some lie with their long axes gently inclined to the vertical. Also some lenticles are sigmoidal in geometry. Most lenticles are unidirectionally cross-laminated.

However, parallel lamination, or even stratification conformable to the geometry of the lenticles also occurs. The siltstone partings can be parallel laminated or rippled.

Vertical or inclined sand-filled cylindrical tubes (trace fossils see Chapter 5) in places destroy the laminations.

3.7.2. Interpretation

The presence of the ripples, and the sorting of the lithofacies into three distinct lithologies indicate that currents in the lower flow regime (Simons et al., 1965) operated during the major part of the deposition, though the mudstones and the siltstones are regarded as largely deposited from suspension. The occurrence of sandstone lenticles within the dominantly finer grained sediments suggest a depleted supply of the coarser sediment and probably of pulsating current activity (Reineck and Singh, 1975). Reineck and Singh (1975) also contend that lenticular bedding is preferentially formed in areas where a change takes place between slack water and turbulent water such as in subtidal and intertidal zones. Tidal conditions are not thought to be responsible however, due particularly to the absence of current reversals in Marsdenian sediments of the study area. Lenticular bedding can also be seen at river floodplain environments (Allen 1965), in delta front areas and lake bottom in front of a developing small delta (Reineck and Singh 1975). Climbing ripples, a product of current velocity and particle size (Coleman and Gagliano, 1965) usually form from migration and simultaneous upward growth of current or wave ripples. Often when much sediment is available especially in suspension, this extra sand quickly buries and preserves the original rippled layers resulting in climbing ripples (Reineck and Singh, 1975). Such climbing ripples are also common features in fluviatile sediments particularly in areas of overbank flow and flood plains (McKee 1966). Symmetrical lamination is indicative of wave activity, however, when both cross lamination and symmetrical lamination are seen with the ripple, the wave activity is regarded as a reworking effect on an original current ripple (Collinson, 1967).

The vertical or inclined cylindrical tubes, interpreted as trace fossils are thought to be indicative of the activity of vertically burrowing organisms which is discussed in Chapter 5.

3.8. LITHOFACIES 8. TROUGH CROSS LAMINATED SANDSTONE

3.8.1. Description

Trough cross laminated sandstone is generally medium-grained, well sorted and gradational with lithofacies 7, Ripple Silty Sandstone. The main difference between the two lithofacies has been pointed out. Occasionally coarse-grained sandstone rich in thin units of coal and coalified plants constitute Lithofacies 8. Lithofacies 8 is characteristically light brown in the colour of its weathered surface and often light grey on fresh surface, with a variable content of mica and carbonaceous material. In many localities the degree to which the stratification is visible depends on the content of mica and carbonaceous material. All gradations are possible between clearly cross laminated, micaceous, carbonaceous sandstone and apparently structureless mica-fine lithofacies 8. This lithofacies is stratified in small, cross laminated sets up to 3cm thick. The sets occur in cosets up to 8m thick. Sets, in vertical section at right angles to the axis of the sets show a trough form. In plan view, the cross strata have a crescentric pattern (Plate 27), popularly called "rib and furrow" -, a useful palaeocurrent directional indicator. This valuable structure has a greater preservation where it is overlain by a finer sediment. In sections parallel to the long axes of the sets, the foresets are gently concave upward or with flat bases. Occasionally, symmetrical ripples are found.

Lithofacies 8 can occur as bottomsets - lying in front of angular foresets (Plate 28) of bigger cross-bedded sets.

Vertical burrows are commonly abundant and can destroy the stratification (Plate 29).

3.8.2. Interpretation

Apart from the occasional symmetrical ripples, Trough Cross Laminated Sandstone is regarded as the product of currents in the lower part of the lower flow regime (Simons et al., 1965). Under such flow conditions, currents usually cause the migration of ripples, and under net sedimentation, linguoid small ripples (Reineck and Singh 1975) generate Trough Cross Laminated Sandstone. Under such a flow condition also, grains of lower hydraulic radius such as mica and carbonaceous materials can be carried further in suspension over the crest of the ripples (Jopling, 1963) and concentrated at the lower parts of the cross laminae such as occurs in the study area. The occasional symmetrical ripples are explicable in terms of wave activity.

3.9. LITHOFACIES 9. PARALLEL LAMINATED SANDSTONE

3.9.1. Description

Parallel laminated sandstone consists of dominantly fine-grained and rarely medium-grained sandstone with occasional variable silt content. Lithofacies 9 is commonly well sorted and clean except for its variable mica and carbonaceous content which imparts a dark grey colour to the otherwise light grey sandstone. Parallel laminated sandstone is gradational with Lithofacies 6, Siltstone; Lithofacies 7, Ripple Silty Sandstone and Lithofacies 14, Horizontal Bedded Sandstone. It is thinly laminated in layers of 1-5mm thick (commonly 1-2mm) with coarse-grained mica flakes and carbonaceous material commonly parallel to the stratification. The visibility of the stratification depends largely on the mica and carbonaceous material. Primary current lineation occurs on bedding surfaces. At one extreme the lithofacies appears broadly light coloured and clearly striped, based mainly on the distinct and rapid alternation of the thick (around 2mm thick) light coloured and thin (1mm thick or less) dark coloured bands (Plate 30). This interlamination with Ripple Laminated Sandstone occurs in places. At the other extreme the lithofacies is broadly dark coloured and poorly stratified due mainly to poor grain size sorting and its greater content of silt and carbonaceous materials. There are all gradations between these two extremes.

Mudflakes and large and comminuted plant fragments are found sometimes lying on the lamination planes.

The lamination planes in some localities show numerous sand-filled elliptical impressions and/or sand-filled ridges which can be straight and simple, curved or even meandering. In the vertical section of some exposures, the stratification laminae can be deformed to various degrees to form series of vertically stacked asymmetrical conical depressions whose open ends face upwards.

3.9.2. Interpretation

Parallel Laminated Sandstone is usually interpreted (Collinson and Banks 1975, Jones 1977) as a product of flow in the lower part of the upper flow regime (Simon et al., 1965), due to sediment movement on a plane bed (Allen 1964). While it is conceivable that the Parallel Laminated Sandstone described here could have formed in a similar way as stated above, it is felt that it formed largely and more probably in the upper part of the lower flow regime, but remained plane-bedded because of its micaceous nature. Apart from the micaceous content, other factors that argue in favour of this model include the localized abundance of carbonaceous material, the dark colour, and silt content of some of the sections and also most notably the occurrence of some sandy interlaminations with rare ripples. This interpretation follows the findings of Mantz (1978) from flume experiments where he showed that while silt-sized silica grains generated ripples and eventually dunes during progressively increasing discharges, fine flake beds of comparable grain size, and under similar flow conditions, did not generate any ripples or dunes but rather produced only parting lineation on a flat surface.

It is felt also that deposition from suspension may have contributed. In such a case, the currents operating above the bed, as is suggested by the grain size, probably did not impinge onto the sediment surface to cause tractional reworking.

Fluctuation in the current strength is regarded as largely responsible for the alternation in grain size, though sediment supply pulsations may have contributed.

The elliptical impressions, the ridges and the depressions (trace fossils) indicate that this facies is particularly susceptible to the activities of burrowing organisms. Usually escape burrows suggest a fairly high depositional rate. Details of the trace fossil are given in Chapter 5.

No absolute environmental significance is attached to this lithofacies from its internal evidence as it appears to occur in a wide variety of clastic environments.

3.9.3. Deformation Structures in Parallel Laminated Sandstone

3.9.3.1. Description

In Light Hazzle Clough (SD 956193) a 30cm thick unit of deformed bedding lies between units of muddy siltstone. Ball and pillow structures (Potter and Pettijohn, 1963) whose common long and short dimensions are 50cm and 20cm respectively and which lie with their long axis parallel to the bedding occur. Some of the pillows are connected but most are completely isolated into distinct ellipsoidal masses (Plate 31). The pillows are stratified in laminae 1-2cm thick. The stratification laminae can be either simple or wavy but generally parallel and curved upwards in accordance with the basal upward geometry. Between adjacent balls, the muddy siltstone flows upwards in the form of tongues.

In Ramsden Clough (SE 121038), the bedding planes of the 17m thick exposed section of the Scotland Flags exhibit multi-directional dips dominantly to the northeast, southwest and northwest (Figs. 31 and 12) with the angle of dip ranging from 5-22^{o}.

3.9.3.2. Interpretation

The restriction of the ball and pillow structures to a distinct and relatively thin horizon and particularly its confinement within undeformed layers indicate that their deformation took place at the time of, or very shortly after, deposition, but in any case before the consolidation of the sediment. Many workers agree that vertical displacement is most prominent in the development of the ball and pillow structure (Kelling & Williams 1966, Reineck and Singh, 1975). Vertical movements usually result in response to the metastable condition of denser deposit overlying less dense sediment.

The probable cause of the multi-directional dips of Ramsden Clough will be made in Chapter 4, after the discussion of its sedimentological context.

3.10. LITHOFACIES 10. TROUGH CROSS BEDDED SANDSTONE

3.10.1. Description

Lithofacies 10 embraces a broad range of medium, coarse and pebbly sandstones, although medium grain size predominates. Pebbles up to 2cm (Plate 32), mud conglomerates and plant remains (Plate 33) and also logs are common (Plate 34). Trough Cross Bedded Sandstone is the most common exposed lithofacies of the Marsdenian sediments of the study area, and it grades into lithofacies 11, Tabular Cross Bedded Sandstone. The common set thickness range is from 0.05-0.8m and cosets thickness ranges from 0.7-15m, occasionally up to 20m. There is often an upward decrease in set thickness.

In vertical sections parallel to the direction of foreset dip the sets can have either planar laterally extensive lower boundary surfaces (Plate 35, cf. Type A, Medium Scale Cross Bedded Sandstone of Baines, 1977) or concave upwards lower erosive bases (Plate 36, cf. Type B, Medium Scale Cross Bedded Sandstone of Baines, 1977). Occasionally, sections similar to the former type are characterized by a series of parallel set boundaries gently dipping 4-8^{o}, (Plate 37) in a direction roughly perpendicular to the true palaeocurrent trend. Sets with planar set bases are generally laterally extensive over distances of up to 30m in length parallel to the palaeocurrent, while those with concave bases have a short lateral extent. In sections perpendicular to the current direction, the bases of sets are more sharply concave upwards, the curve tending to be symmetrical about a vertical axis, though asymmetrical in few cases such as Woodhouse Quarry (SE 062397) and Riddlesden Quarry (SE 068430). In these places, the southwest margin is consistently longer and steeper (18-20^{o} compared to 10-12^{o} of the southwest margin). The relationships between the internal structures of this lithofacies as seen in an east-west and northeast-southwest section of Branshaw Quarry (SE 031402) are shown in Plates 39A and 39B. In plan view the margins of the sets are parallel sided though with curved closures, concave in the direction of foreset dip (Plate 38). The troughs are commonly between 50cm and 5m wide and 0.05-1m thick. Wider and narrower troughs are respectively longer and shorter. A rough correlation appears to exist between set thickness and trough widths.

The scale of the foresets is often between 0.2-2cm thick and when viewed perpendicular to the current direction the foresets can be either concordant or discordant to the trough base. Foresets are generally tangential to the base in sections parallel to the trough axis, and discordant to the sides of the trough in plan view. Foresets are sometimes graded. In sandstone of medium grade particularly, fine-grained sands rich in mica and carbonaceous materials accumulate in the toe of set. The maximum foreset dips, measured at the tops of the sets often range from 15-25^{o}. Plant fragments which can often be associated with slight deformation of the sedimentary structures often lie with their long axes parallel to the trough axes. In general large plants lie parallel to the bedding. Locally, however, numerous such plants can pile randomly as if dumped. An exception to the parallel orientation of the plants occurs at Harper Clough Quarry (SD 717316) where a 1.4m diameter trunk is preserved in growth position (Plate 40) on top of the intensely bioturbated Trough Cross Bedded Sandstone, occurring within the depth interval 12-16m (Fig. 17). Twelve pitted roots (Plate40 and 41) whose average length, and long diameter are 60cm and 35cm respectively branch out from the tree.

3.10.2. Interpretation

The Trough Cross Bedded Sandstone described here is considered to have formed during the migration of trains of dunes, under conditions of net sedimentation (Allen 1963). Such bed forms occur when the flow is in the upper part of the lower flow regime (Simons et al., 1965). An alternative hypothesis proposed by Harms et al. 1965) for the generation of Trough Cross beds involves scour and fill mechanism whereby spoon-shaped scours are caused by the turbulence elements which are independent of the separation zones vortices of dunes. This mechanism is not thought to have applied in the case of the cosets as the relationships among the component sets do not indicate the random scouring of troughs in space and time as is implied by the process, rather it is thought to have operated during the generation of the solitary sets.

Shallowing and slow change in flow strength or discharge (Jones 1977), is probably responsible for the upward decrease in the size of troughs.

Trough Cross Bedded Sandstone, both those with laterally extensive sets and others with laterally restricted sets, are considered to be products of very similar hydrodynamic condition except that while the Trough Cross beds of the latter type are thought to be produced at velocities or stream powers higher than that needed to generate those of the former type (cf. Reineck and Singh 1975). The genesis of the sets characterised by a series of gently dipping, parallel set boundaries will be discussed in the account of the Delta Top Association. The concentration of finer grained sandstone and mica at the toes of some foresets is probably due to the hydraulic sorting of the grain sized related to the particle trajectories during bedload flow over the lee face of dunes (Jopling 1963).

With regard to the slight deformation of bedding associated with plants, it is common for certain sedimentary structures overlying wood remains to contort when the wood rots. Also the preservation of a big wood trunk in its growth position indicated that sedimentation around it took place quickly before the plant had time to rot after its death, and in fact even if the plant continued to grow after the onset of sedimentation its life span was probably not large.

3.11. LITHOFACIES 11. TABULAR CROSS BEDDED SANDSTONE

3.11.1. Description

Tabular Cross Bedded Sandstone whose set thicknesses range from 0.05-2m (commonly 0.20-0.50 m) occur, both as solitary sets and as cosets. The facies is gradational with lithofacies 10; Trough Cross Bedded Sandstone which it resembles in many features. Sets of 1-2m thickness are relatively rare. Cosets up to 24m thick occur and in some (Plate 42) both trough and tabular sets coexist. Tabular cross bedding occurs in medium to very coarse-grained sandstone with pebbles up to 2cm long. Plant fragments are common. Locally numerous coalified rafts stacked together and oriented with their long axes parallel to bedding planes occur. Allochthonous coals are locally abundant particularly at Fletcher Bank Quarry (SD 805165). Logs up to 1.2m length and over 30cm wide (Plate 43) occur. Individual sets are commonly parallel sided and can be traced extensively laterally, quite often for distances upwards of 20-30m parallel to the dip direction before they wedge out.

The erosion surfaces at the bases and tops of sets are generally flat and usually very near to the original horizontal.

The foresets whose bases may be angular (Plate 44), tangential (Plate 45) or even concave (Plate 46) range in thickness from 1-5cm, commonly 2-3cm thick. Foresets can be graded or massive.

Mudclasts whose long diameter can be up to 7cm and which locally still retains its clayey nature, are aligned with their long diameter parallel and along the cross-bedding planes. These are best illustrated at Bracken End Quarry (SE 194433, Plate 47). Maximum foreset dip dominantly ranges from 20-25^{0}. Sets made up of dips of this value, which are hereby referred to as high angle foresets (using the terminology of High and Picard 1964) are frequently short. Sets containing low angle foresets occur also (Plate 48). Their foresets are often parallel sided and they are laterally extensive. All dips are generally undirectional. Details will be given in the account on directional structures in Chapter 6.

The following 2 variations from the common tabular cross bedded sandstone described above occur.

1. At Wicking Crag Quarry (SE 049374), the base of a set of a localized tabular cross bedded sandstone is associated with a coset of lithofacies 10, Trough Cross Bedded Sandstone whose trough width ranges from 1 to 10cm and thickness 0.5-8cm. Troughs occur within the basal 10cm of each foreset. The axis of the lower boundary of the troughs is perpendicular to the dip direction of the foreset in which it is associated (Fig. 35, Plate 28).
These Trough Cross beds are transverse intrasets (Collinson 1968). The upper boundary of the intraset is hard to pick due to the fact that its coset climbs the foresets to different levels.

2. In the northeast parts of Lumb Quarry (SE 031217), a 15cm thick set of Tabular Cross bed, is separated from an underlying 28cm thick set by a concave upwards erosional surface. However, when traced 5m southwestwards, roughly in a downcurrent direction, these two sets grade into one another to form one thicker set in a manner shown in Figure 36. Following Jones (1977) this erosional surface occurring within individual sets of cross beds are termed internal erosional surfaces.

3.11.2. Interpretation

Traditionally, cosets of Tabular Cross Bedding have been interpreted as the product of bedforms with straight crestlines, such as transverse bars, linguoid bars or sandwaves, which seem to be produced at a lower flow strength than dunes (Harms et al. 1975). Sandwaves have slip faces capable of generating large scale tabular cross beds. There is a concordance in scale between the tabular cross beds of this study and the heights of sandwaves reported in literature. For instance the height of the slip faces of the linguoid bars of the Tana River varies from 0.5 to 2m (Collinson, 1970).

As regards the intrasets at Wicking Crag, they could be produced during the falling water stage over a linguoid bar. Usually lowering water stage reduces the strength of the separation eddy and under such a condition small troughs whose flow is perpendicular to the foreset dip of its associated foreset can form (cf. Collinson 1970, Fig. 27).

Alternatively the intraset may be the product of bedforms with a lobate crestline. Because much of the crestline will be skewed relative to the mainflow, direction, the separation streamlines will be redirected obliquely, intersecting the avalanche face at the angle equal to the angle of skew of the avalanche face with respect to the main flow direction (cf. Allen 1968, Fig. 9-15). If the angle of skew is great enough, a spiral separation flow will develop (Collinson 1970), and most intrasets will be oriented obliquely to the main avalanche face. Intrasets seen here could also be produced by other processes like rise in water level, or by superimposed bedforms (McCabe and Jones 1977).

The alignment of the long axis of the mud clasts along and parallel to the cross-bed planes is in accord with Sengupta's (1966) contention that the preferred orientation of pebble long axes was parallel to the dip direction in the middle part of a set.

The merging downdip of one tabular set with an immediately overlying thinner set could well be just a feature random effect on bedform behaviour, or more probably due to the faster migration of the smaller bedform relative to an underlying larger one on which it is superimposed. This phenomenon is probably in consequence to an increase in water depth (McGowen and Groat, 1971).

3.11.3. Deformational Structures in Tabular Cross Bedded Sandstone

3.11.3.1. Description

In Riverside Cemetary Quarry (SE 053237) at Sowerby Bridge a deformation structure occurs in a unit directly on top of Lithofacies 13, Scour based sand bodies, and it is separated from an overlying unslumped Lithofacies 11, Tabular Cross Bedded Sandstone by a scoured surface. Followed from the cliff-faced Quarry southwestwards for some 140m along the cross-bedding dip, the deformed unit decreases in thickness from some 6m to 4-3m. This progressive decrease is largely due to the steep dip (18^{0}/260) of the scoured upper contact. Associated with this, the intensity of the slumping decreases remarkably southwestwards, particularly from the prominent complexly contorted zone in the middle 15m length of the quarry (Fig.37, Plate 49) to a mildly contorted part dominated by deformed climbing ripples, and occasional undeformed cross-bedded equivalents at the southwestern end of the Quarry (Plate 49).

The latter reveals the original tabular cross bedded character of this unit. Also the fold attitude appears to change from mostly overturned and recumbent types to simply inclined types southwestwards (Plates 51 & 52).

The base of the deformed unit is also erosional and irregular and it is locally marked by abundant mud clasts.

The contorted structures display considerable diversity in form and dimension. Most of the contorted bodies consist of several types and sizes of both antiformal and synformal folds, including hook-shaped overfolds. All degrees of cohesion occur, ranging from gently inclined undeformed foresets through gently flexed and crenulated laminae to zones in which only broken and isolated folds occur (Fig. 37). Balls encircled by concentric stratified layers occur. Long and short dimensions of such balls are commonly 3m and 1.5m respectively and the scale of the laminae is often 8-15cm thick.

Orientation of the folds

The parameters measured are the same as in section 3.6.3.2. The fold axis orientations and the axial plane dip directions are presented both in a two-dimensional azimuthal histogram (Fig. 38) and in a three-dimensional stereonet (Figs. 39 & 40) based on the consideration that whereas the two-dimensional plot would allow a faster appreciation of the distribution of the data involved especially where there is some appreciable degree of scatter (Fig. 40), such a plot alone may mask the wide dispersion due to plunge, especially where the value of plunge is significant as is the case under consideration. The fold facing direction is also shown in Figure 38 . The abundance of primary directional and/or way up features made the assessment of the sense and style of closure possible.

3.11.3.2. Interpretation

As with the interpretation made in section 3.6.3.2, these deformation structures are regarded as slump structures. However, unlike the case of section 3.6.3.2. they are considered to be syndepositional based mostly on the homogeneity of the materials involved, but also on the style of the folds. They are thought to be of sedimentary origin based on the following considerations; the deformed bed is sandwiched in between undeformed units, the presence of erosional upper and lower contacts (Kelling and Williams 1966), the absence of any associated tension cracks and cleavages (Woodcock 1976b), and also the wide range of deformational structures present (Rupke 1978). As regards the adjustments that generated the structures, lateral translation is considered most dominant based on the following observations; the abundance of anticlinal structures especially the recumbent overfold with subhorizontal axial planes at the northeast parts; the fairly good concordance between the orientation of the deformed bodies and the palaeocurrent pattern (Fig. 41) obtained from the primary sedimentary structures in the associated unslumped sediments; the strong unimodal orientation of the axial folds, reinforced by the consistency in attitude of the anticlinal closures. Also the lateral variation in unit thickness is regarded as suggestive that at least some of the deformation occurred at a free surface, presumably the sediment-water interface.

Based on these various pieces of evidence, it is felt that slumping in this locality could have been due to any of the following two factors.

1. Large weight of a fastly deposited sand pile. In this case, the slumping probably initiated at a sediment water interface, probably on a slight slope of which this locality was a part, due largely to a rapid deposition of a thick pile of sand. The weight of this resultant sand mass which leads to fluidisation and thixotropy (cf. Rupke, 1978) is capable of generating failure and consequent movement. The predominance of climbing ripples at the southwestern parts is pertinent to this interpretation, particularly as they are absent in both the underlying and overlying unslumped zones. The faster deposited thick and heavy sand mass seems to have overridden the underlying sediment pile deposited normally.

2. Combined influence of a weak sediment and a steep slope. The weak sediment, in this case, is probably due to rapid deposition and liquefaction. This influence is thought to have caused a local slump mass to cascade down the steep slope and to over-ride the sediment pile deposited on a more stable slope. Such a slope advantage was probably lost southwestwards, during the continuous deposition that followed, resulting in decreased southwestern intensity of slumping. Also the subsequent sedimentation did not experience slumping probably due also to the loss of the slope advantage.

3.12. LITHOFACIES 12. LARGE SCALE CROSS BEDDING

3.12.1. Description

The large scale cross bedding discussed here consists of sandstone occurring in cross bedded sets ranging in thickness from 2m to over 16m. Admittedly, there is a natural continuum between this facies and Lithofacies 11, Tabular cross bedded sandstone. However, the decision to discuss it separately is largely due to its prominence wherever it occurs because of the scarcity of sets of 1-2m thickness range. Although it is also formed of coarse to pebbly sandstone, units formed by medium-grained, micaceous sandstone are more common. The latter are locally bioturbated. Even a fine-grained ganister (see p.148) exposed at Laggin Platt Quarry (SE 087093) is large scale cross-bedded. The most prominent sets of this lithofacies observed in Central Pennines are at Diggley Quarry (SD 110094, Plate 53), Warland Wood Quarries (SD 948203) and Tower Hillside (SD 906261 , Plate 54), where the set thicknesses are over 16m, 9m and 5.2m respectively. The bases of the exposures in Diggley and Warland Wood Quarries are not seen. Set thicknesses of 34m and even 40m were seen in a somewhat similar lithofacies by Collinson (1967) and McCabe (1975) who worked on the Kinderscoutian sediments within the Pennine basin. It must be emphasised however, that the Kinderscoutian sediments involve extremely coarse and pebbly sandstones which are generally coarser than the Lithofacies 12 of this study.

At Ramsden Clough (SE 121038) and Parkwood Quarries (SE 070409 and SE 067406), a set of cross bedding of this facies can be followed with reasonable confidence for up to 1.2km and 0.5km respectively along the foreset dip direction though the exposures are not continuous. It is difficult to ascertain the true width of cross bedding because of lack of exposure. McCabe (1975) feels that widths can be over 1km. The 4 types of foresets recognized within this facies are as follows.

1. High Angle Foresets. These are angular foresets with dips commonly 15-25^{o} but rarely up to 30^{o} (Plate 54). Individual foresets ranging in thickness from 2-15cm (commonly 5-10cm) are also undirectional.

2. Low Angle Foresets. Foresets are parallel sided, laterally extensive and with a common thickness range of 45-90cm. On closer examination of weathered parts smaller stratification of 1-7cm thickness occurs. All foresets are undirectional and have a maximum dip of 10-12^{o} (Fig. 42).

3. Concave Upward Foresets. Individual foresets are commonly 2-20cm thick, though on less weathered parts they may appear to range from 50-76cm thick (Plate 55). The bases are usually finer-grained, thinner stratified, gradational (Plate 56), and may often appear horizontal usually 5-9^{o} as against 18-25^{o} measureed at their topes. A 50cm thick topset occurring at Park Wood Quarries consists of horizontally stratified units.

At Diggley Quarry, both types 2 and 3 foresets occur. The type 2 foreset which consists of an 8.5m thick package of essentially conformably cross bed is separated from an overlying 7.7m thick package of type 3 foresets by a 10cm thick trough cross laminated sandy mudstone drape (Plate 57). These packages are termed "subsets" based on the following considerations. a. Lack of evidence of erosional activity at the base of the upper 7.7m thick package. b. Absence of an abrupt change in character between the two packages. c. Ease of reference. Both foresets labelled "A" and "B" in Figure 42, constitute the major basal set of large scale cross beds in Diggley Quarry. Intrasets of trough cross laminated sandstone occur within the foresets at both Diggley and Park Wood Quarries. The trough thickness of these intrasets are commonly 0.3-0.5cm and 1-3cm wide. These cosets are up to 30cm thick. The trough axis orientation of these sets are oblique to the direction of their associated large scale foresets.

4. Sigmoidal Foresets. At Kebroyd Quarry (SE 040210), a 2.6m thick solitary cross bed is characterized by foresets which are sigmoidal in shape (Plate 58). The thickness of these foresets ranges from 4-5cm. Maximum foreset dip is 20^{o}. Southeastwards, however, that is, in the down dip direction, these foreset laminations become progressively less distinct, and based on the basal geometry of the poorly exposed structures, it appears that these sigmoidal foresets grade to Lithofacies 10, trough cross bedded sandstone.

Internal erosion surfaces which extend completely or most of the way through the set and separate two groups of adjacent foresets occur in lithofacies 2. The major ones are typified by those in Diggley Quarries, Ramsden Clough Section and Tower Hill side (Plates 53, 59, 54).

Diggley Quarry: The strata within this quarry are classified into "A", "B" and "C" types for ease of reference. Foresets within "A" and "B" have been discussed. Beds within "C" are numbered i-xi also for descriptive purposes. Four concave upwards internal erosion surfaces numbered 1-4 occur in the manner shown in Figure 42 and Plate 53 .

Salient features of the relationships are as follows:

(1) The concave upwards foresets of "B" are truncated by "Ci" bed.

(2) The base of "Cii" beds which suddenly dips steeply southeastwards, that is, in a downstream direction, truncates the base of "Ci", and maintains similar dip and strike as the underlying foresets. Further southeastwards it becomes irregular and scours progressively the upper foresets of "B" (Plate 53 , Fig. 42). This is the internal erosion surface "number 1". Flutes are abundant at the base of the subset directly overlying the surface.

(3) Foresets overlying the internal erosion surface "number 1" dip more steeply (14^{o}) than their surface and so are progressively discordant to it.

(4) Internal erosion surface "number 2" starts from the base of "Ciii", and maintains the same dip and strike as the underlying cross-beds and also converges towards the underlying "number 1" internal erosion surface.

(5) Beds "Ciii" to "Civ" which are tabular and horizontally

stratified in the northwest parts of the quarry because progressively cross bedded southeastwards. Their foresets are fairly concordant to the underlying internal erosion surface "number 2".

(6) Internal erosion surface "number 3" which originates from the base of "Civ" truncates the underlying cross beds. Foresets overlying "C3" are concordant to it. These foresets are in turn truncated by the base of "Cv" which forms the internal erosion surface "number 4". Foresets overlying the latter are concordant to it.

It must be emphasized that the most striking feature in this quarry is the grading southeastwards of the 0.20-0.40m thick horizontally bedded "C" units to large scale cross beds.

Ramsden Clough: Internal erosion surface "E" truncates the underlying cross beds down into the horizontal beds below these cross beds. (Plate 60 & 62, Figs. 43 & 45. Similarly, the internal erosion surface "EE" truncates the underlying cross beds.

Other striking features observed in this section are; the lenticular beds which overlie directly the internal erosion surface "E"; the undulatory foresets overlying the lenticular beds; the southeastern increase in set thickness of the cross beds; the overlapping behaviour of the undulatory foresets in a downstream progression, that is southeastwards (Plates 60-63, Figs. 43 to 45). Crest to crest length of these undulations is up to 15m, though the length decreases upwards and southeastwards.

Tower Hill Side: Both the basal and the upper internal erosion surfaces truncate the foresets of their adjacent cross beds.

3.12.2. Interpretation

Large scale cross bedding similar to the type described here and within the same or adjacent basin have been variously considered to be deposits of Gilbert type deltas (Collinson 1967, 1969), in-channel alternate bars (McCabe 1975, Jones 1977) and in-channel products of large scale asymmetrical current ripples (Baines 1977). McCabe (1975) contends also that channel confluence deltas, channel infill deltas and large sandwaves are some other possible origins of the Namurian (R1) Large Scale Cross Beds of the Pennines.

The features of the large scale cross beds of this study that are relevant to considerations of the bedform type that probably generated them include the following; texture of the lithofacies in their different localities; the prevailing natural continuum between the cross bed types; the existing lateral facies relationships (horizontal bedding or trough cross bedding grading laterally to large scale cross beds); the sigmoidal geometry of some of the foresets; the intrasets; the numerous internal erosion surfaces and most important, the relationship between the foreset dip directions of the lithofacies and those of their other associated directional features.

A suitable model for this lithofacies in this study should account for these component features. Such an all encompassing single model is presently difficult to envisage, so a number of alternative models seems most applicable.

In the present case, while LF12 in some localities are considered to be products of accretion on a slip face, in other localities they appear to be lateral accretion sediments.

The concordance in scale between the large scale cross beds of this study and the heights of sandwaves reported in literature, particularly those reported by Coleman (1969) which are up to 17m high and others, reported by Lane and Eden (1940) in the Mississippi which are 6.7m, makes sandwaves a probable generating bedform of this structure. Sandwaves generally have slip faces capable of generating large scale cross beds. Alternatively, the lateral facies gradation mentioned above coupled with the scale of the foresets argue more in favour of alternate bars. The associated internal erosion surfaces resemble those of McCabe (1975) and Jones (1977) and are thought to be low stage modification feature which formed in a similar manner to that described by McCabe (1975) and Jones (1977). A more detailed discussion of the possible models for the generation of LF12 and their associated modification features, will be given after a consideration of LF12 in its sedimentologic context has been made.

3.13. LITHOFACIES 13. SCOUR BASED SAND BODIES

3.13.1. Description

Scour based sand bodies are formed mainly of coarse to very coarse-grained and pebbly sandstone, though occasionally they consist of medium-grained sandstone. Where clearly developed they often portray trough-like base and a flat top (Plate 64). The "Large scale trough-shape bedded sandstone" (Okolo, 1982, in press) belongs to this lithofacies. Their

Table 16. Features of Scour Based Sandbodies

Location	Thickness (m)	Width (m)	Stratification Type	Other features (Dip and dip-direction, etc.)
Riverside Cemetary Quarry	0.85	16	Conformable with base	
	1.50	10	" " "	
	2.10	10	" " "	
	2.40	20	Massive. poor weathering	East margin 22/260
	1.10	10	Discordant with base	Wood at base
	0.80	5	" " "	Wood at base
	2.00	20	" " "	
	1.50	15	Conformable with base	
	1.50	10	" " "	
	2.00	20	" " "	
	1.00	10	" ' "	
	0.80	5	" ' "	East margin dips 28/270^{o} ' " " 22/270^{o}
	0.85	12	" " "	West " " 22/270^{o}
	2.10	20	Massive	Wavy. West margin dip 10-42/270^{o}
	2.45	20	"	" " " " " ' "
Tower Hill Side	2.0	9	Massive	
	2.0	12	"	
	2.5	15	"	Logs, mud and sand clasts
	1.0	12	"	
	1.0	10	"	
	1.0	8	"	
	1.5	10	"	
	1.0	6	"	
	1.0	6	"	
	1.0	6	"	
	1.5	13	"	
Gorpley Clough	0.85	2	Trough Cross Beds	
	1.0	3	" " "	
	0.57	3.7	" " "	
	0.85	3.4	" " "	
	0.85	4.4	" " "	
	1.40	3.7	" " "	
	1.00	4.8	" " "	
	0.70	3.14	" " "	
	1.00	3.40	" " "	
	0.60	2.0	" " "	
	0.80	2.0	" " "	
Fletcher Bank	5	30	Tangential foresets	

Table 16. Features of Scour Based Sand Bodies

Location	Thickness (m)	Width (m)	Stratification type	Other features (Dips and dip directions etc.)
Wicking Crag	1.62	23.2	Trough Cross beds	Trough base is symmetrical (18° each side). Abundant trace fossil (Pelecypodechnus) at base. Log
	1.75	33	" " "	West margin of trough base 30/110. Log composed of sandstone clasts, wood. Overlain by Solitary Planar Cross bed, which grades laterally to trough cross beds.
	2.57	29.4	" " "	Symmetrical trough base. East margin dips 10/290. Abundant wood.
	3	30	" " "	
	3	30	" " "	
	1.17	13	" " "	Bodies 6-10 overlie 1-5
	0.74	10	" " "	
	0.84	6.0	" " "	
	1.20	8	" " "	
	1.20	6	" " "	
Pule Hill	4-5	49 (possibly up to 105)	Conformable to base	Prominent Foresets 30-162cm thick (South margin with thicker foresets) but stratification down to 10cm occur
	3.86		" " "	Foreset scale 5-40cm
	3.30			Cross beds in this set can be traced laterally for up to 200m
	2.50			
	2.50			
	2.50			

Table 17 Features of Lenticular Sandstone Beds

Location	Thickness (m)	Width (m)	Internal Stratification Type	Other Features
Fletcher Bank Quarry	0.50	12	Horizontal Beds	Loaded base with relief of 20cm
	0.60	4	Trough cross laminated sandstone	
	0.70	6	Trough cross laminated sandstone	
	0.60	30	Trough cross laminated sandstone	Arthrophycus; Planolites abundant (see p.)
Buckden	0.50	20	Trough cross laminated sandstone	
Holmbridge Quarry	1.5	25	Massive	
Readyshore Scout Quarry	0.60	25	Horizontal beds	Scour base with relief of 35-40cm. Loaded.
Braithwaite Quarry	1.16	21	Trough Cross laminated sandstone	Pelecypodichnus abundant (see p.). Abundant plant remains

prominent scour base with relief of 1.5m and more (Plate 65), are frequently characterised by lag concentrates composed variously of logs of wood (Plates 66 & 67) quartz and mud conglomerates (Plates 68 & 69), interbedded . thin shale and coal zones (Plate 70), some of the latter being coalified wood (Plate 71). Various types of sandstone filled ridges (trace fossils) are locally abundant at the bases of these sand bodies. Fuller accounts of these traces will be given in Chapter 5. The common width of each of the bodies, where both margins are exposed is 20m, though widths as small as 2m and as large as 50m (possibly up to 105m) occur (Fig. 47). The common thickness range of each trough is from 1m to 5m, occasionally down to 0.7m or up to 11.6m (Fig. 48, Plate 77). The sandbody dimensions decrease upwards commonly (cf. Wicking Crag SE 049374). Table 16 shows the dimensions of the various scour based sand bodies at the different locations.

Except in the uncommon case of the Fletcher Bank Quarry (SD 805165), a number of these bodies coalesce and form a sheet sandstone (using the terminology of Campbell, 1976) with only the broadly curving upward bedding planes remaining as evidence of the constituent bodies (Figs. 49 & 50). Even in the case of the Fletcher Bank Quarry, the solitary sand body occurs within a thick sandstone unit.

The following three types of stratification occur within these bodies.

1. Symmetrical Cross Beds. Here, the cross strata are essentially concordant to the lower bounding surface (Plates 65, 72 & 73, 74). At Riverside Cemetary Quarry (SE 053237) the cross-strata whose thickness ranges from 3-15 cm and which are parallel sided and

also maintain their thickness all through their length, resemble Figure 7 of McKee (1957) in geometry. These cross-strata are best exposed in the weathered parts of the rocks. In Pule Hill (SE 032105) Lithofacies 10, Trough cross-bedded sets, up to 40cm thick occur within these large scale cross strata (Plate 42). Out of context, these Trough cross beds, termed intrasets (Collinson 1967) appear no different from cross bedding of lithofacies 10. The flow directions of these intrasets were measured at the top surfaces of the two distinct units labelled "A" and "C" in Figures 47 and 48 which are best exposed respectively at the northern and southern parts of Pule Hill. The dip direction of the large scale foresets and the orientations of the plants exposed in the same plan view and locations as the intrasets were similarly measured and plotted in Figure 51. There seems to be a preferred intraset direction dominantly to the southwest but also northwest, that is, roughly towards the direction of strike of the Large scale cross bed, and fairly more in accordance with the plant orientation though still oblique to it. The intrasets resemble the "scoop-shaped intraset" of McCabe (1975) both morphologically and in their relationship to the large scale foreset.

Also at Pule Hill, prominent erosional surface labelled 1" and internal erosional surfaces "2" and "3" (Fig. 48) occur at the north-west-southeast quarry face. Dip of "1" which is 9^{o} towards the top falls progressively to 2^{o} towards its base before it loses its identity. In contrast, the dip of "2" is 18^{o} and consequently converges towards "1". Also prominent on this face are the large scale foresets that occur between the erosional surfaces and above "2". The foresets between the erosional surfaces which are fairly concordant to "1" are truncated by "2" in the southeast parts. Foresets overlying "2" are concordant to it but are truncated by "3" which is in turn overlain concordantly by foresets.

2. Asymmetrical Cross Beds. The cross strata here are asymmetrical to the lower bounding surface (Plate 75), and resemble Figure 8 of McKee (1957). The usual thickness of the foresets ranges from 3-30cm. Lithofacies 10, Trough Cross bedded sandstone occurs as intrasets within the foresets. Morphologically, these intrasets resemble the "scoop-shaped intraset of McCabe (1975).

3. Massive. Some of the sand bodies appear massive (Plate 66).

4. Trough Cross Beds. Cross bedding similar in all respects to Lithofacies 10 constitutes the dominant structure of these bodies in some localities such as Wicking Crag (SE 049374), and the lower parts of Riddlesden Quarry (SE 068430) (Plate 76).

A combination of these structures can occur, though rarely. For instance, the parallel stratified lower parts of the bodies at Wicking Crag suggest that conformable strata are partly involved. Intrasets of trough cross laminated sandstone occur locally within the trough cross beds. Also, localized occurrences of tabular cross beds which grade laterally to trough cross bed occur at Wicking Crag.

3.13.2. Interpretation

Scour based sand bodies are regarded as small channels scoured out within larger channels based largely on the shape of their base, the prominent relief of scours the lag concentrates, particularly the large logs of wood and the mud and quartz conglomerates. Involvement of big trough cross-beds due to big bedforms are not ruled out all together even though they are not thought to have contributed much based on the features of these structures mentioned above. The small channels envisaged here are considered as usual phenomena in fluvial environments (Reineck and Singh 1975). Detailed discussions of these channels and the interpretations of their infill deposits and modification features will be given in the account of Delta top sediment.

3.13.3. Deformation Structures in Scour Based Sand Bodies

Faulting and slumping occur within this lithofacies. A discussion of these structures will be made after an establishment of the context of the scour based sand bodies.

3.14. LITHOFACIES 14. HORIZONTAL BEDDED SANDSTONE

3.14.1. Description

This facies is formed mainly of medium-grained to less commonly coarse-grained sandstone which is generally well sorted and clean looking. The sandstone is stratified in the parallel beds between 1-8cm thick which are laterally traceable over several meters (plate 78). The strata which are often parallel either to an underlying or overlying bounding surface are generally horizontal except if they are in close proximity to an erosional surface when they may lie parallel to that surface (Plate 79). Undulatory bedded zones with sharp bases occur locally (Plate 78).

Although Lithofacies 14 closely resembles Lithofacies 9, parallel laminated sandstone, it differs from it mainly in grain size, but also in having less mica and carbonaceous material and in the scale of its stratification. Primary current lineation was not observed, probably due to a lack of extensive well exposed bedding planes. Lenticular units may occur within it (Plate 80). In fact in Ponden Clough (SD 980364) and Readyshore Scout (SD 942198), a substantial thickness of Lithofacies 14 appears to consist of a coalesced sheet of wedge-shaped units with internal horizontal stratification. The bases of some of these bodies are even scoured (Plate 79), portraying a minimum scour relief of some 30cm. Some of the bases contain loads (Plate 81), flutes, elongated longitudinal ridges. Symmetrical longitudinal furrows and ridges were seen only at Readyshore Scout.

Meandering horizontal or surface trails (trace fossils) which are exceptionally abundant at Ponden Clough and Bare Clough (SE 018309) characterise the bedding planes of this lithofacies generally. Full details of these trace fossils are given in Chapter 5 . Plant remains mildly deform the strata locally.

3.14.2. Interpretation

In view of the grain size and the clearly developed plane bedded structure of the sandstones, it is felt that strong traction currents operating in the lower part of the upper flow regime (Simons et al., 1965) probably deposited this lithofacies. It seems unlikely that the lower phase of the plane beds could deposit such coarse beds of this lithofacies. The presence of flute marks also supports the idea of a powerful erosive turbulent current. The ridges and furrows are other scour marks that indicate the strength of the current.

3.15. LITHOFACIES 15. LENTICULAR SANDSTONE BEDS

3.15.1. Description

This facies is dominated by medium-grained and occasionally fine-grained well sorted sandstone. Where well developed the bed is commonly lenticular and portrays a rather biconvex geometry (Plates 82-84). In many localities where the lateral extent of the exposure is restricted, it commonly appears wedge-like. Although the lenticular bedded sandstone resembles Lithofacies 13, scour based sand bodies because of their common lateral disappearance, their texture, ratio of thickness to length, and context differ. As regards context, units of Lithofacies 15 often occur in isolation among finer sediments. The lenses commonly range in thickness from 0.15m to 0.50m and in length from 20m to 30m. The general tendency is for them to be comparatively thin but wide (Table 17). The 1m thick, 21m long and the 0.60-0.70m thick, 6-4m long lenticular bedded sandstone seen at Braithwaite and Fletcher Bank Quarry respectively are exceptional.

Lenticular bedded sandstone can be either horizontally stratified, trough cross laminated or massive.

Scour marks can also occur at the bases of this unit. Vertical burrows and various types of horizontal trails occur. These trace fossils are discussed in detail in Chapter 5 .

3.15.2. Interpretation

The grain size and structures of Lithofacies 15 suggest a fairly rapid deposition from some kind of erosive turbulent, but laterally restricted current. Based on the usual context of Lithofacies 15, it appears that the sudden incursion is within an environment accumulating fine-sediment. As will be further discussed in Chapter dealing with Interdistributary Complex Association, this fine sediment frequently shows evidence of current activity and so also indicates a shallow water origin. A fast deceleration of such a flow can generate the massive beds and localized sinking into the underlying less dense muddy substrate may account for the occasional loads seen at some beds.

3.16. LITHOFACIES 16. PARALLEL SIDED SANDSTONE.

3.16.1. Description

This facies is commonly a medium to coarse-grained well sorted sandstone which is occasionally micaceous. It is generally well bedded in tabular units of variable thickness from 5cm to 50cm. It is often isolated in fine-grained sediments (Plate 7A). Upper bedding surfaces are commonly irregular due to current and/or wave ripples (Plate 7B) and the sharp erosive bases may contain flute marks (Plate 7A), loads and groove casts. They are either massive, trough cross bedded or trough cross laminated.

Vertical burrows and several meandering trails on the bedding surface occur.

3.16.2. Interpretation

This facies is thought to represent sudden incursions of sediment laden waters, sometimes involving sheet flows, into a quiet environment normally collecting sediments from suspension. The lithofacies is similar to Collinson's (1967) and McCabe's (1975) sharp based sandstones which the former author interpreted in a similar manner. The real nature of the currents depositing these beds is not clear.

Following Walker (1965), Collinson (1967) contends that the sharp based sandstones may be due to turbidity currents, however, unlike Walker (1965), he feels that such a flow may have taken place under a shallow water or even subaerially, as long as the slope and the thickness of the flow are large enough to provide high bed shears. McCabe (1975) prefers storm currents to turbidity currents for the generation of the sharp based sandstones based mostly on his interpreted environmental context of the lithofacies, as will be elaborated later. "Storm layers", which McCabe (1975) regards as an analogue to the sharp based sandstone of his study area, occur when the build up of water near the shore during a storm, leads to a strong undercurrent which transports the coarse sediments of the shore area seawards.

Because the understanding of the sedimentological context of Lithofacies 16, is pertinent to the consideration of its genesis, a further discussion of which mechanisms seem most appropriate will be held until Chapter 4, dealing with Interdistributary Complex Association.

3.17. LITHOFACIES 17. MASSIVE SANDSTONE

3.17.1. Description

This facies consists of coarse to very coarse-grained, poorly sorted sandstone with pebbles up to 3cm in long diameter. It is commonly rich in mud and sandstone clasts which are scattered randomly though more frequently, they are concentrated near the basal erosion surface. Angular clasts of mud, siltstone and even sandstone up to 15 x 10cm (long and intermediate diameters) have been recorded (Plate 68). Log casts are also common, particularly at the sandstone bases where they can be locally abundant and even in an intimate association with concentrations of pebbles and angular blocks of sandstone and siltstone (Plate 87). This facies generally has erosive base (Plate 88). Its beds which are generally structureless, except for rare irregularly oriented fractures, range in thickness from 0.40m to 11m. It is possible, however, that some of these beds are amalgamated without portraying identifiable evidence of their original component parts.

3.17.2. Interpretation

The internal features of this lithofacies such as the very coarse texture, particularly the large and angular clasts of sandstone, siltstone and mudstone appears to suggest that whatever current deposited it must have been powerful. Some of the theories considered by McCabe (1975) and which appeal to the writer as possible formative mechanism for massive sandstone include the following:

1. Sudden freezing of traction current carpet with a high concentration of dispersed grains (Walker 1975).

2. Deposition in certain upper flow regime conditions as discussed by Walker (1965) and Harms and Fahnestock (1965).

3. Deposition in the metastable field (Walton 1967) resulting due to such a rapid deceleration of current that prevents equilibrium bed form from developing.

4. Non-turbulent sediment gravity flow, involving finalized-, grain-, and debris- flows which deposited by mass emplacement and consequently became structureless (Middleton & Hampton, 1973).

5. Intense bioturbation which frequently destroys the sediment fabric.

Rust (oral comm. September 1981) contends that scour troughs incised at the basal part of a slip face of a large bed form are capable of providing a nucleus for massive bed generation. According to him, the

3.17.2. Interpretation

The internal features of this lithofacies such as the very coarse texture, particularly the large and angular clasts of sandstone, siltstone and mudstone appears to suggest that whatever current deposited it must have been powerful. Some of the theories considered by McCabe (1975) and which appeal to the writer as possible formative mechanism for massive sandstone include the following:

1. Sudden freezing of traction current carpet with a high concentration of dispersed grains (Walker 1975).

2. Deposition in certain upper flow regime conditions as discussed by Walker (1965) and Harms and Fahnestock (1965).

3. Deposition in the metastable field (Walton 1967) resulting due to such a rapid deceleration of current that prevents equilibrium bed form from developing.

4. Non-turbulent sediment gravity flow, involving finalized-, grain-, and debris- flows which deposited by mass emplacement and consequently became structureless (Middleton & Hampton, 1973).

5. Intense bioturbation which frequently destroys the sediment fabric.

Rust (oral comm. September 1981) contends that scour troughs incised at the basal part of a slip face of a large bed form are capable of providing a nucleus for massive bed generation. According to him, the components of the downstream currents which are directed towards themselves and in the orientation parallel to the strike of the slip face can render the sediments within the scour structureless.

Further discussions of which of these mechanisms probably applied to Lithofacies 17 will be held until the discussion of the Channel Association in Chapter 4 .

3.18. LITHOFACIES 18. PINCH AND SWELL SANDSTONE.

3.18.1. Description

This lithofacies consists of clean-looking, fine-grained, well-sorted sandstone, which is sometimes so compact as to resemble ganister. Its unique feature is its bedding style which pinches and swells to form a pattern of interlocking lenses (Plate 89). For instance, at Hazel Greave type section (SD 915240) certain beds swell to 100cm and within a lateral distance of 4m pinches to 70cm. It is common to see a bed of 40cm thick pinching to 20cm within a lateral distance of some 2-3m. Stratification within the beds is generally conformable with the basal and top boundaries. The common thickness of these internal strata is 4cm. The lower boundary surface is erosional, as suggested by the rare mud flakes seen in between some few beds. When a section at right angles to section portraying the pinch and swell geometry is exposed unidirectional cross beds are shown. Patchy exposures of this face occurs at Hazel Greave type section. Beds occur generally in a composite form.

Plant fragments occur, and bottom surfaces may show rare vertical burrows.

3.18.2. Interpretation

Apart from the scale, and the erosional base of the component beds, the geometry of this lithofacies appears similar to the Kappa-Cross-stratification of Allen (1963). Following McKee (1939), Allen interprets these structures as due to the migration of trains of linguoid small ripples. The necessary sediment supply criterion for the generation of the structure, is that in the time taken to advance its own length, each ripple receives by deposition from suspension a volume of sediment greater than the volume of the ripple body and under such circumstances the ripple bodies are not themselves eroded but added to on both lee- and stoss-sides (Allen, 1963). There seems no reason, why this mechanism cannot apply in the case of Lithofacies 18, provided that a greater current velocity than in Allen's (1963) case obtains, after all scale is the only major distinguishing factor between large-, and small-scale linguoid ripples (Reineck and Singh 1975).

3.19. LITHOFACIES 19. TURBIDITE-LIKE SANDSTONE

3.19.1. Description

This lithofacies is dominated by a well sorted medium-grained sandstone with variable amounts of fine-grained sandstone and siltstone. Beds are commonly 5-15cm thick, but range from 1 to 50cm. Bed amalgamation is common, though thin mud-flake horizons often pick out the original bed thickness. With few exceptions, the bed boundaries are generally planar and parallel, hence the beds are generally tabular, except a few which are lenticular and disappear and reappear at the same horizon.

Internally, the following intervals of sedimentary structure occur within the beds: massive ("A" of Bouma 1962), lower and upper parallel stratification ("B" and "D" respectively), mudstone ("E"). Different beds portray various combinations of these intervals, however they generally follow the vertical order of Bouma (1962). For instance at Gorpley Clough (SD 915235), using Bouma's (1962) notations, while the "BDE", "BE", "AE" and "BD" sequences predominate, the "ADE", and "BDE" successions occur more frequently in Wessenden Reservoir exposure (SE 062087). With the exception of the trough cross-bedded sandstone occurring within the current ripple lamination interval at Gorpley Clough, it appears that there is a general absence of the interval. Allen (1970) also reported the occasional presence of cross-bedded sandstone above the lower parallel stratification interval. The massive interval shows grading only occasionally (at Gorpley Clough only), probably due to the general well sorted nature of the sandstones (Bouma 1964). The scale of stratification of the lower interval parallel lamination is commonly 0.2-1.0cm. The upper interval of parallel lamination usually compares with either lithofacies 5a or 5c, Parallel Laminated Mudstones and siltstone or mudstone with siltstone laminations respectively. Where this interval is absent, distinct sandstone beds show mutually erosive contacts, hence the constant amalgamation.

The chief current directional features seen in these beds include flute marks (Plate 90), longitudinal furrows and ridges (Plate 91), prod and bounce marks (Plates 92 & 93). These features are preserved as moulds on the soles of the beds.

Although this lithofacies resembles parallel sided sandstone superficially, the absence of a vertical gradation in the internal sedimentary structures, and the general rarity of sandstone beds' amalgamation in the latter lithofacies appear to distinguish them in the study area. A similar distinction was also reported by Jones (1977) who detected even gradational bases in some Parallel Sided Sandstone of the Roaches Grit Group of the southwest Pennines. Collinson (1967) and McCabe (1975) however detected internal stratification resembling that of turbidites in the sharp based sandstones, a similar lithofacies.

3.19.2. Interpretation

No significant differences occur between the sequences seen here and those of other workers on the Namurian succession of this basin (Walker 1966, Collinson 1967, McCabe 1975, Jones 1977) which they attributed to turbidity currents. It is therefore suggested that similar processes of sedimentation operated during the deposition of Lithofacies 19, and the vertical sequence of the sedimentary structure reflect a waning flow (Harms & Fahnestock 1965, Walker 1966). The general absence of the rippled top may be either because the rapid deposition of Lithofacies 19, or the large amount of sediments settling from suspension, prevented ripples from forming (Jones 1977). Admittedly, cross bedding is rare in turbidite sequences. However, it has been observed in some turbidites (Hubert 1966, Maschalko 1964) and Allen (1970) contends that such rare cross-bedded units represent dunes, which are formed at larger stream powers than ripples. The tool marks were produced probably by the plant fragments carried by the facies.

A further discussion of any depth connotation implied by this lithofacies will be made within the framework of the Lithofacies Association in Chapter 4.

3.20. LITHOFACIES 20. SEATEARTHS AND COALS

3.20.1. Description

Seatearths generally underlie the Marsdenian coal seams in the Central Pennines and are therefore treated together in this work to reflect this proximity. The common characteristic of all the seatearths is the presence of carbonized rootlets oriented in vertical or inclined position.

The following types of seat earths occur.

Type 1: Fireclay: This consists of unbedded, sticky, soft, medium light grey clay which frequently portrays a conspicuous yellowish grey to brownish grey colour. These colours are probably due respectively to alteration to jarosite or staining of limonite.

At Tower Hill side (SD 906261), a vertical gradation within fireclay consists of a basal 20cm thick medium grey unit overlain by a 50cm thick yellowish grey to brownish grey fireclay which in turn is overlain by a 20cm thick dark grey fireclay. The latter is gradationally capped by a 30cm thick coal.

Fireclays are the second most common seat earth encountered, and their common thickness ranges from 15-90cm, though up to 134cm thick at Fletcher Bank Quarry (SD 805165).

Type 2: Ganister: This consists largely of a very light grey or white lithographic, fine-grained silica-rich sandstone usually hard and rich in carbonized traces of rootlets. The best developed example occurs in the 8m thick Laggin Platt Quarry (SE 087093) at West Nab.

Type 3: Seat earth proper: This is the most common type seen. Its colour ranges from light grey to brown and their grain size ranges from siltstone through medium-grained sandstone to even coarse-grained sandstone seen locally. They can be bedded or unbedded. At Harper Clough Quarry the 130cm thick seatearth composed of muddy siltstone is rich in ironstone nodules, probably siderite nodules, and it is also intensely bioturbated. The best developed rootlets seen in the field occur at Warland Wood Quarries (SD 948203) and Fletcher Bank Quarry (SD 805165). At Warland Wood where a 140cm thick medium scale cross bedded sandstone constitutes this lithofacies, vertically oriented rootlets up to 30cm long (Plate 94) and horizontally oriented Stigmaria over 50cm long and some 6cm in diameter (Plate 95) are abundant. Stigmaria roots up to 8cm in diameter together with their attached thinner rootlets are well shown in Fletcher Bank Quarry (Plates 96 & 97). The coarsest seatearth seen occurs within the height interval 58-60m (Fig. 17) in Cowloughton Clough (SD 965414). This interval which is essentially coarse-grained at the lower parts and finer at top is rich in rootlets and vertical burrows (Plate 98). The thickness of the seat earth proper ranges from 0.4-2.5m.

Three types of coal, ranging from the silty or muddy types through those rich in vegetable matter to the ordinary house-coal occur.

Type A Coals (silty-muddy coals). These are commonly thin, 4-5cm thick commonly, rich in silt or mud, unbedded, usually dirty and crumbly.

Type B Coals (vegetable rich coals). These are commonly black and characteristically rich in leaf impressions or other plant structures. Black coloured, carbon-rich sediments (Plate 99) are allocated to this coal type only when they lie directly on top of seatearth. This is because they are physically similar to Lithofacies 4, Carbonaceous mudstone. A better èxample of this coal type occurs in the height interval 294·5-295m of Fletcher Bank Quarry which overlies a 1.34m thick seat earth directly. Numerous plant structures occur in it. The thickness of this coal type is commonly about 15cm, though 80cm at Cowloughton Clough.

Type C (ordinary house coal or bituminous coal). These are the commonest types seen. They are black, hard, shiny, bedded and often portraying yellowish grey or brownish grey stains. The prominent stratification thickness is about 1cm though they can be 0.2-0.3cm thick. Cubical pieces are produced on breaking.

The coals are generally gradational with its adjacent lithofacies. A single couplet of coal seat earth is most common but double or even rare triple couplets may occur.

3.20.2. Interpretation

The penetration and disturbance of sediments by roots and rootlets is usually interpreted as a diagnostic indication of an ancient soil (Read & Watson 1962), in which plants grew in-situ. The coals associated with such soils are regarded as autochthonous. The seat earths are the palaeosoils for only the earliest plants, because the latter plants probably rooted themselves in the rotting mat of earlier plant material (Collinson, 1978).

The various coal thicknesses together with the different coal types appear to suggest that various degrees of subsidence occurred within the Central Pennine area. Silty and muddy coals probably reflect areas that had no good establishment of growing peat, while the relatively thick may have formed in areas that underwent steady greater subsidence to have allowed a thicker accumulation of vegetable matter. These types of coals probably did not experience as great a post-depositional compaction as those that formed the ordinary house-coals and so have not lost their plant structures. The fining upwards tendency of some seatearths probably reflects the decreasing current energy operating after the onset of plant colonization due to the inhibiting effects of the plant (Wilson, 1965). The unbedded seat earth may be due to the distructive actions of either the rootlets or the burrowing organisms. The siderite nodules could be due to precipitation from slightly reducing ground water in a permanently saturated soil. The horizontally lying stigmaria reflect the shallow rooting system of the Marsdenian trees.

CHAPTER 4: FACIES ASSOCIATIONS

4.0. Introduction

There is currently an increasing emphasis on the adoption of a genetic approach to facies analysis by workers interested in basin analysis based on the recognition of the fact that groups of process-related sedimentary facies often have environmental significance. Such related facies have been variously termed Facies Assemblage, Facies Association (Collinson, 1967; Baines, 1977), Depositional System (Scott & Fisher, 1969), Genetic Increment of strata (Busch, 1971). Facies linked genetically by processes can be related to an environment using modern analogues. Studying the organization both in space and time of these processes deduced from the individual facies which constitute the Facies Association helps one greatly in deciphering the environment of deposition.

The 20 lithofacies described in Chapter 3 have been grouped into the following 5 broad facies associations.

Deep Water Association

Delta Slope Association

Distributary Channel Association

Interdistributary Complex Association

Abandonment Association

Each association is described and interpreted in turn. Boundaries of the associations are discussed at the start of each lithofacies association section.

Although the basis for the further subdivisions of each of these associations is discussed later under the section dealing with each sub-association, it is necessary to pre-empt the discussion by presenting here the following outline for the subdivision. This approach is adopted so that the terminologies used for the subdivisions, both in the text and and its complementary figures 12, 14 to 17, 52 to 59 & 77 to 82 will be presented as shown below, for the convenience of the reader. Terminologies of the subdivisions as used in the figures are shown in brackets.

1. Deep Water Association (Marine, Turbidites. 0-122m level, sequence e, Fig. 16).

2. Delta Slope Association

   (i) Finer Lithofacies Subassociation (Marine, Prodelta, occasionally plus Turbidites).

   (ii) Coarser Lithofacies Subassociation (Mouth Bar, or Mouth Bar Area).

   Channelized Parts of (ii) (Channels within Mouth Bar Area).

3. Distributary Channel Association

   (i) Major Channels (Distributary Channels)

   (ii) Fluvial Sheet Sand Bodies (Distributary Channels)

4. Interdistributary Complex Association

   (i) Alternating tabular bedded sandstone and mudstone units (Bay, Levee).

   (ii) Alternating lenticular sandstone beds and mudstone units (Crevasse Splays in Bays; Small streams/channels in Bay).

(iii) Channel Unit cutting into sharp based tabular sandstone (Crevasse Channels in Interdistributary Bays or on Levees).

(iv) Gradationally based sandstone units with irregular tops (minor mouth bar).

5. Abandonment lithofacies Association

(i) Coal on Seatearth (Marsh; Swamp).

(ii) Unfossiliferous Mudstone (Bay).

(iii) Fossiliferous Mudstone (Marine).

A summarized presentation of these associations and their components is made in figures 12B, 14B to 17B, where they are termed palaeoenvironments. These figures should be referred to constantly while reading the following discussion on Facies Associations. The legend for the notations used in Figure 12, 14 to 17, 52 to 59 and 77 to 82 is the same and is presented in the page opposite Figure 16.

4.1. DEEP WATER ASSOCIATION

4.1.1. Description

This association is rare, and occurs only in Fletcher Bank Borehole (SD 805165). Its recognition as a separate association is deemed necessary because the constituent sandstones which are bounded above and below by lithofacies 2, Fossiliferous Mudstone, do not form part of any gradational facies transition such as is found in the Slope Association. The top of this association is taken at the top of the highest marine band that occurs below the first major channel. This level (122m-level) is only 6m below the base of a continuously thick homogenous siltstone. For ease of reference, the latter level is adopted as the boundary.

The association commences with a 20m thick grey silty, very micaceous, fossiliferous mudstone, the basal 5m of which is occupied by R. gracile goniatite band and the remaining thickness is characterised by frequent incursions of R. bilingue goniatite bands (Fig. 16). While R. wrighti dominates the goniatite bands occuring within the 25-50m level, Dimorphoceras sp. and Anthracoceras deans are more prevalent in the 80-122m depth interval.

Frequent intercalations of turbidite-like sandstone, lithofacies 19, whose common range in thickness is from 1-5m and grain size from medium to coarse sand occur. Both sandstone and siltstone can be micaceous. Mudstone conglomerates are often particularly abundant near the bases of sandstone beds, such as at the 47m level, although they can occur within the unit as well. Many sandstone units have sharp, often erosive bases such as at the 44m level. The irregular base at the 57m level is associated with load structures. Middle parts of sandstone beds can be either rippled or wavy.

Plant remains, particularly Calamites, can be abundant. Some of the plants are coalified as at the 63 to 64m level. Deformed units occur often and slumps are common particularly at the 50m and 55m levels.

4.1.2. Interpretation

The sharp erosive bases, the abundant mud clasts, particularly those concentrated at the bases, the plant remains and the lithology, all suggest that the thick sandstone units may be channel fill deposit.

This interpretation is similar to the one Collinson *et al.* (1977) suggested for the comparatively much thicker bedded turbidites of a similar age occurring within the Marsdenian succession west of Blackburn. They also had a better control on the succession, as the rock units are exposed. They contend also that the thinner bedded turbidites and siltstones in the Blackburn sequence represent deposition in overbank settings or the latest stages in channel abandonment. A similar interpretation would seem to apply for the 1-3cm thick turbidite units of this association. Some of the sediments also moved by slumping, probably due to rapid deposition.

Since most of the mudstone sediments appear to be associated with goniatite or other marine fossils, the mudstone is considered to represent sourceward ponding of sediments, perhaps during sea-level rise. However, what is not known is the extent to which these interbedded marine mudstone are originally hemi-pelagic background sediment or have a very dilute turbidity current origin.

4.2. DELTA SLOPE ASSOCIATION

4.2.1. Limits of the Association

The boundary between this association and the underlying Deep Water Association as far as the Pule Hill Interval at the Fletcher Bank Section is concerned has been discussed in Section 4.1. In all other localities the base of *R. gracile* marine band constitutes the base of the association of this interval. The base of the bands of

R. bilingue typical and R. bilingue late constitutes the base of the Delta Slope Association in Pule Hill Interval and Hazel Greave Interval respectively. In each of these 3 Intervals, the base of the first major Fluvial Channel is regarded as the top of its Delta Slope Association. However, where a deposit interpreted as of Bay origin occurs below this first fluvial channel, the base of such Bay sediment is preferred as the top of the association.

4.2.2. Description and Interpretation

As is already clear from section 4.2.1., this association embraces the Scotland Flags Mudstone, the Pule Hill Mudstone, the Hazel Greave Mudstone and the often flat bedded fine- to medium-grained lower leaves of Scotland Flags, Pule Hill Grit and Hazel Greave Grit. Also, as is outlined in above section 4.0. these sediments have been grouped into the following two sub-associations for ease of discussion.

Finer lithofacies sub-association
Coarser " "
(Channelized Parts of Coarser Lithofacies Sub-association)

The description and interpretations of each of these sub-associations are given in the order in which they are listed above.

4.2.2.1. Finer Lithofacies Sub-association

Limits of the Sub-association

The lower boundary of this sub-association is the same as the base of the Delta Slope Association discussed in Section 4.2.1. Its upper boundary is gradational and it is picked arbitrarily often at the highest traceable mudstone underlying the beginning of the siltstone background sediment. This contact is usually preferred, because due to creep, it is often more reliable to define such arbitrary boundary by the highest occurrence of a particular lithofacies type, rather than the lowest (American Commission on Stratigraphic Nomenclature, 1961).

Description

The sediments forming this sub-association are predominantly fine-grained, commonly involving Lithofacies 1, Unfossiliferous Mudstone, commonly rich in plant fragments; 2, Fossiliferous mudstone, 5, Mudstone and Siltstone and 6, Siltstone. In general therefore, this sub-association is mudstone dominated. However, interbedded with these mudstone units at several localities are turbidite-like sandstone, lithofacies 19, whose features have been discussed in section 3.19.1, and whose component beds are commonly 1-20cm thick.

The usual vertical order in which the lithofacies are introduced into the sub-association is for lithofacies 1, Unfossiliferous Mudstone to follow lithofacies 2, Fossiliferous Mudstone gradationally before lithofacies 19, Turbidite-like Sandstones intrude sharply, when they occur.

For instance, in localities within either the Scotland Flags Mudstone or the Pule Hill Mudstone that do not contain Turbidites (Figs. 12, 14-17), the typical vertical lithofacies order is for some 10-30m thick Unfossiliferous Mudstone to overly Fossiliferous Mudstone, Lithofacies 2, whose thickness ranges commonly from 0.5-3m. A similar vertical lithofacies order occurs in the Hazel Greave Mudstone as is typically shown in d (Fig. 14), b (Fig. 15) and b (Fig. 17), however the sub-association is comparatively thinnest here, being frequently composed of some 10m thick lithofacies 1, Unfossiliferous Mudstone, which overlies lithofacies 2, Fossiliferous Mudstone, ranging in thickness from 0.3-2.5m. The 22m thickness of this sub-association occurring in Hazel Greave Mudstone of Readycon Dean Section (a, Fig. 12), Wessenden Reservoir Section (b, Fig. 12) is uncommon. In the sub-associations containing Turbidites, which appear to be restricted to the Scotland Flags Mudstone and the Pule Hill Mudstone (Figs. 12, 14-17), the height of occurrence of the Turbidite Sandstone above lithofacies 2, Fossiliferous Mudstone ranges from 0-20m. The turbidite-like sandstone may be developed either as single thin beds separated by thicker beds of mudstone (sequence a, Fig. 12) or in amalgamated units of several beds, with mudflakes horizons or thinner mudstone units occurring between the composite sandstones (sequence b, Fig. 12, sequence g, Fig. 16). Both types may occur in one sequence, and when they do, the single beds which are commonly 1-5cm thick are restricted to the basal parts while the amalgamated sand units whose component beds are commonly 10-20cm thick occur at higher stratigraphical levels. This thickening-up tendency is best developed at the Scotland Flags Mudstone in Wessenden Reservoir Section (Fig. 52), which also coarsens upwards. Even though the turbidite sandstone unit within the Scotland Flags Mudstone in Readycon Dean section occurs as single beds, the sequence thickens and coarsens upwards (Fig. 53). There is a rough overall thickening-up of turbidite sandstone beds at Gorpley Clough Finer Lithofacies Sub-association (0.40m level, Fig. 54), and in the Scotland Flags Mudstone in Sabden Brook (sequence c, Fig. 17). No obvious vertical organization is detected in the turbidite sandstone units occurring within the following sections listed according to their time-stratigraphical intervals.

(a) Scotland Flags Mudstone: Sequence b, c, e, f (Fig. 14).

(b) Pule Hill Mudstone: Sequence b, f (Fig. 14).

Lithofacies 5, Mudstones and Siltstones, occurring in the turbidite rich Finer Lithofacies Sub-association within the Scotland Flags Mudstone or the Pule Hill Mudstone often constitutes Bouma's (1962) upper interval of Parallel Lamination in their associated turbidite Sandstones. In the Non-turbidite Finer Lithofacies Sub-association within the Scotland Flags Mudstone, the Pule Hill Mudstone and the Hazel Greave Mudstone the siltstones of either Lithofacies 5 or 6 commonly occur as thin isolated parallel interlaminae which are more often seen towards the top of the Sub-association, though they can occur at other parts of the sub-association.

The Finer Lithofacies Sub-association in Longworth Valley Exposure SD 689157, Figs. 16, 29 & 30, Plate 18) deserves special discussion particularly because of the proximity of the siltstone units to Lithofacies 2, Fossiliferous Mudstone but also because such a discussion helps to emphasise the sedimentological context of its slump unit discussed in detail in section 3.6.3. This 1-2m thick slump unit occurring some 1m above Lithofacies 2, Fossiliferous Mudstone (see Section 3.6.3.), commences the sequence of 1-8cm thick siltstone interbeds into Lithofacies 1, Unfossiliferous Mudstone. These siltstone beds appear different from the thin turbidite sandstone interbeds discussed above principally due to lack of flutes and tool marks and absence of Bouma (1962) sequences, but also owing to lack of unit amalgamation. Although each bed superficially appears as a homogenous entity, a polished slab shows its heterogenous nature as rare thin darker coloured mudstone interlaminae occur which are virtually parallel to the rest of the lighter coloured, dominant siltstone laminae. The R. superbilingue band caps the sequence as shown in Figures 16, 29 and 30.

While the common vertical order, as is clear from the above discussion is for Lithofacies 2, Fossiliferous Mudstone to be confined to the lowest part of the sequence for each of the chronostratigraphical intervals, it must be emphasised that in few localities, Lithofacies 2 can also occur within the main body of the sequence as is shown in the following vertical sections.

(i) d, e of the Scotland Flags Mudstone (Fig. 15).

(ii) f of the Pule Hill Mudstone (Fig. 14).

(iii) e of the Pule Hill Flags Mudstone (Fig. 15).

(iv) b, c of the Hazel Greave Mudstone (Fig. 16).

Interpretation

The well developed mudstone sequence in the lower part of this sub-association, together with their associated turbidite and non-turbidite sandstones and including the coarser Lithofacies Sub-association (discussed in the next section) which occur at their top, are considered to be deposits laid down on a prograding slope. The prograding slope envisaged here may be that of a delta, following the model noted in modern deltas by Fisk and others (1954), Allen (1965) as well as in ancient deltaic deposits by Barrel (1914), Kelling and George (1971), though slopes developed in front of any other form of shoreline with abundant sediment supply is not ruled out.

The mudstones probably represent slow deposition from suspension at the base of the slope and beyond with virtually no traction. They are the prodelta facies of several workers. The plant debris occurring in the unit is in consequence of sediment input being direct from the distributaries. While the prodelta in most of the localities is non-marine except for their lowest thin marine base, represented by the marine bands, substantial parts of some of the prodelta were at times marine. This quiet energy prodelta area was intruded by turbidity currents at several localities.

The presence of Prodelta turbidites similar to the types envisaged here has been widely reported in literature (Moore & Clark, 1970; Flores, 1972; McBride et al., 1975; Kepferle 1978). The Prodelta turbidites of this study are considered as products of sediment-laden discharge issuing from the distributary mouth areas during flood periods which was denser than their receiving basin waters and so entered the basin as turbidity currents. A modern analogue which provides evidence that turbidity currents can be generated at river mouths comes from the correlation of submarine cable breaks with times of high river stages for the Magdalena and Congo rivers (Heezen, 1955; Heezen et al., 1964). Phenomena like this makes one feel that muddy waters discharged from such floods can be sufficiently dense to form hyperpycnal flows (i.e. turbidity currents) at the delta front, and the flows continue down slope into progressively greater depths (McBride et al., 1975). Flores (1972) contends however that turbidite like sandstone could indicate a relatively short distance to the source area and also that sediment-carrying distributaries reached directly to the delta front with little trapping effect along the way.

While the turbidite like sandstone within the Scotland Flags Mudstone in Wessenden area (b, Fig. 12) may be near to or within the locus of active deposition probably within the upper parts of a channel based on the erosional bases, the lenticular geometry, the massive character and the lithology, the section at Rake Dike (c, Fig. 12, 4-15m level) probably represents deposition in an overbank setting. The latter interpretation is based on the fine-grained texture, gradational boundary, intense bioturbation and tabular geometry of the beds. In general therefore, the Prodelta turbidites of this work are regarded as periodically intruded sediments into an otherwise quiet water regime.

While the thin mudstone units occurring in between turbidite sandstones are regarded as probably turbiditic (Bouma E interval), principally due to their context and their internal lamination, but also because of their thickness which compares with some of their adjacent sandstone units, the thick sandstone units separating the single turbidite bed at the lower parts of the sub-association are treated as probably non-turbiditic. A thin mudstone layer on top of a turbidite sandstone unit could have been deposited by the same turbidity current responsible for the sandstone unit (Kuenen 1964, Piper, 1978).

The issue of the genesis of the mudstone units occurring in turbidite successions is controversial. Moore (1970) strongly feels that such mudstone units are mere pelitic intervals deposited at a slow rate fairly similar to the original rate of deposition in the mudstone environment into which the turbidite were intruded. He contends that while the turbidite layers are geologically instantaneous, taking only a matter of hours to deposit, the mudstone layers have a much slower rate of deposition which represents the true rate of deposition of the sequence. In contrast, Piper (1978) states that muds deposited from large turbidite currents accumulate rapidly but episodically, and form beds10 to 10^3mm thick in periods ranging perhaps from hours to months.

The siltstone interbeds occurring within the Hazel Greave mudstone of sequence 'a' (Fig. 16) are considered as Density current deposit, McCabe (1975) and Jones (1977) have already suggested that density currents operated during the formation of the delta slope of the Kinderscout Grit Group and the Roaches Grit Group respectively. Bates (1953) contends that density currents occur where the sediment laden river water has a greater density than the receiving basin and so flows down the basin slope. A river flowing into a fresh water lake or reservoir, provides conditions conducive for the generation of density currents, such as has been described from lake Mead (Gould, 1960) and Lake Geneva (Shepard and Dill 1966). River generated density currents are closely related to periods of increased discharge and suspended load during floods (Gould, 1960; Lambert et al., 1976), and the tabular beds are considered to be formed during individual flood events which transported sand down the delta slope. Similar to the case of the thin Prodelta turbidites, a situation is envisaged whereby rivers, at periods of high discharge are capable of continuing down the slope as density currents. Some of the criteria listed by Jones (1977) for distinguishing density current deposits from sediments of "classical" turbidites which the present author deems vital for this discussion include the following

(i) Absence of flutes and tool marks

(ii) No Bouma sequences

(iii) Common Bioturbation

(iv) Lack of unit amalgamation

(v) Unit base which may be gradational

(vi) Variable grain size through the bed

Apart from criterion (iii), all the other features are displayed by the deposits of the Longworth Valley Helmshore. Even though the presence of slump structures such as occurs in this locality is not mentioned by Jones (1977) and other workers to be an essential of a density current deposit, it is thought that the density current origin for the slump layer is justified.

Summary

The Finer Lithofacies Association is regarded as a prograding delta slope, the mudstone areas of which is considered to be the prodelta area while the intercalated sandstone units are commonly turbiditic but also a result of Density current deposition. Both the turbidites and the Density current deposits are intruders into an otherwise quiet energy prodelta environment.

4.2.2.2. Coarser Lithofacies Sub-Association

Limits of the Sub-association

This sub-association immediately overlies the Finer Lithofacies sub-association and so its lower boundary is the same as the upper boundary of the Finer lithofacies sub-association discussed in section 4.2.2.1. The top of the coarser lithofacies sub-association is the same as the top of the Slope Association discussed in section 4.2.1.

Description

This sub-association is usually sand dominated, though in its fully developed sequences it is commonly composed of the following lithofacies; 5, Mudstones and Siltstones; 6, Siltstones; 7, Rippled Silty Sandstone; 8, Trough Cross Laminated Sandstones; 9, Parallel Laminated Sandstone; 10, Trough Cross Bedded Sandstone; 11, Tabular Cross Bedded Sandstone and 14, Horizontal Bedded Sandstone.

The sequence shown at the 24-44m level in Rake Dike (Fig. 12) is regarded as typical for this sub-association both because its full succession is exposed, but also because its exposed large lateral extent (some 200m continuous northeast-southwest section exposed) affords an opportunity for lateral lithofacies changes to be studied. Its lower parts are composed of Lithofacies 5, Mudstones and Siltstones which makes the selection of the lower boundary difficult and fairly subjective. However, the frequent occurrence of rippled siltstone lenses within this zone is usually a good clue to its identity. A 1.5m thick layer of Lithofacies 7, Rippled Silty Sandstone succeeds Lithofacies 5. Sandstone units here occur dominantly as rippled lenticles of length 0.3-1 cm and thickness 0.2-0.5cm within distinct siltstone beds that range in thickness from 5-30cm separated by mudflake horizons. A 4m thick Lithofacies 14, Horizontal Bedded Sandstone which is laterally continuous for as much as 200m gradationally overlies Lithofacies 7, Rippled Silty Sandstone, and the Horizontal beds are in turn overlain transitionally by some 10m thick Lithofacies 11, Tabular Cross Bedded Sandstone. The occurrence of the marine band on top of these cross-beds is a good indication of the end of the sequence. Other sequences exhibiting this orderly coarsening upward tendency are listed in the following order of their chronostratigraphical intervals.

(i) e, d, in Scotland Flags Interval (Fig. 14).

(ii) c in Pule Hill Interval (Fig. 12).

(iii) a, d, in Pule Hill Interval (Fig. 14).

(iv) g in Pule Hill Interval (Fig. 16).

(v) e, f, in Pule Hill Interval (Fig. 17).

(vi) d in Hazel Greave Interval (Fig. 14).

(vii) b in Hazel Greave Interval (Fig. 15).

(viii) b in Hazel Greave Interval (Fig. 17).

One general observation is that the ripples are more common in their lower parts, and from base to top the grain sizes often range from very fine to medium size. The sandstone beds commonly range in thickness from a few centimetres (1-5cm) in the lower parts to 2-4m in the upper part. Lithofacies 9 and 14, Parallel Laminated Sandstone and Horizontally Bedded Sandstone respectively are often most abundant and are commonly characterized by trace fossil Olivellites, the details of which are given in Chapter 5. Where both Lithofacies 9 and 14 occur in one vertical sequence, the former generally underlies the latter. One common observation within these 8 sequences listed above is that each of them is truncated by a channel in a similar manner as occurs in Figure 6 of Flores (1981). The discussion of these channels is reserved for the following association dealing with Distributary Channel Association.

The Coarse Lithofacies Sub-association shown in the 20-28m level in Park Wood Quarry (d, Fig. 15) in the 7.8-19.2m in Sunny Bank Cutting (b, Fig. 16) and in the 28-38m level in Hodge Clough (c, Fig. 16) deserve some special mention because of their peculiarity. The development in the latter two sequences are similar but are different from the Park Wood sequence, even though all the sequences portray good coarsening upwards tendencies. In Sunny Bank Cutting for instance, tabular beds of parallel laminated siltstone commonly of 0.2-1cm thickness range, which imparts a striped appearance to the rock, are restricted to the lower 1m thick zone of coarser Lithofacies Sub-association immediately overlying Lithofacies 2, Fossiliferous Mudstone (Plate 100) while tabular beds of siltstone of 4-10cm thickness range occupies the upper 8.5m thick part of the succession (Plate 16). Coal on seat earth caps this sequence. The striking aspects of the Park Wood Quarry are: the gross lenticular nature of the overall sand body (Fig. 19), the good coarsening upward sequence, the vertical sequence of interval sedimentary structures involving ripple dominated lower parts to Lithofacies 10, Trough Cross bedded upper parts and the well developed 30cm thick coal on a 63cm thick seatearth underlying R. bilingue marine band.

It is noteworthy that in certain localities, the Coarser Lithofacies Sub-association intimately involves channels within itself. Good examples of these occur in the following localities:

(i) Ramsden Clough (SE 121038) 25-40m & 82.5-84m level (d,Fig.12)

(ii) Scotland Flags Quarry (SE 033268, Fig. 55, Plate 2,).

(iii) Bare Clough (SE 018309) 42-44m level (a, Fig. 14; Plate 80).

(iv) Readyshore Scout (SD 942198, Plate 79).

(v) Heyden Road Exposure (SE 097035, Plate 88).

Channels are recognized in this sub-association both from the nature of the beds filling the channel (cf. Kepferle, 1978), the presence of prominent or good channel margin or lags. The lithofacies of these channels may or may not be similar to those of the adjoining lithofacies constituting this sub-association. The following brief description of these channels hopes to highlight their properties.

a. Channel in Scotland Quarries. Except for the northern margin of this channel which is exposed no other channel in this sub-association shows its sides. This northern margin is concave upwards (Plate 101) and dips 30^{o} to the southwest. The channel is filled by Lithofacies 10, Trough Cross bedded Sandstone which is medium grained, clean looking and very well sorted. The maximum thickness of the fill is 2m. Set bases within this fill are horizontal and the channel top is distinctively horizontal (Fig. 55). The channel cuts into and also is overlain by intensively bioturbated sandstone (Fig.55). Based on the reconstructed morphology of these channels, working from the geometry of the lateral extent of the exposed margin, and parts of the channel, the estimated width is 100m.

b. Channels in Ramsden Clough. 3 channels which are vertically in mutually erosive relationship to one another occur in the Scotland Flags as is shown in 27-40m d, Figure 12 and Figure 57. The basal 1.5m thick part of the lowest channel is massive while its overlying

5.5m thick portion is occupied by Lithofacies 14, Horizontal Bedded Sandstone which out of context is undistinguishable from the lithofacies underlying the channel. The upper 2 channels, each of which is 50cm thick are characterized by prominent erosional bases marked by abundant mud clasts. Each of them is filled by medium grey muddy siltstone, with lenses of clean, medium grained, well sorted sandstones whose tops are irregular due to wave ripples. It is noteworthy that tops of sand units which are either within or outside these channels display multidirectional dips (Fig. 57) as was discussed in section 3.9.3.

Also at Ramsden Clough within 82.5-84m level (d, Fig. 12), a 2.5m thick Pule Hill Grit channel occurs (Plate 113). The channel is infilled with a single set of medium-scale cross-bedding which appears to have infilled the channel at a high angle to the presumed channel axis. The measured relief of scour of this channel is 25cm. The channel is overlain by a 2m thick unit of Lithofacies 8, Trough Cross Laminated Sandstone.

c. Channel in Readyshore Scout. The channel here is characterized by remarkably pronounced trough shaped scour bases; marked by mud clasts; symmetrical ridges and furrows; loads with relief of up to 4cm; tiny ridges (? flutes) whose length ranges from 0.5-1cm, width 0.3cm and relief of 0.2cm; plants and lenses of mudstone of long diameter commonly 40cm, short diameter 8cm. Two distinct channels mutually erosive into themselves occur. However based on the presence of mud-flake horizon between, it appears that they might have been separated originally by a mudstone unit. Each of them is some 1.5m thick and is filled by Lithofacies 14, Horizontally bedded Sandstone whose characteristics are the same as those of the adjoining lithofacies to the channels. Each of these channels could be traced laterally for up to 30m before further being covered.

d. Channel in Bare Clough. This channel is characterised by local thickening within Lithofacies 14, Horizontally Bedded Sandstone - as is shown in Plate 80.

e. Channels in Heyden Road Exposure. The 2 channels recognized here are each characterised by prominent erosional surfaces (Plate 88) whose measured relief of scour is 40-60cm, marked by flutes whose gentle end has an azimuth of 140^{o}. Each of the channels is filled by lithofacies 17, Massive Sandstone. The lower channel is 40cm thick and the upper one is 60cm thick and each is cut into Lithofacies 8, Trough Cross Laminated Sandstone (Fig. 56). Each of these massive sandstone units is traceable laterally in the northwest-southeast direction for up to 50m before being lost to cover.

The ball and pillow structure and the multi-directional dips on tops of sandstone units discussed in section 3.9.3. occur within this Coarser Lithofacies Sub-association.

Interpretation

The order in which lithofacies are introduced into this sub-association is consistent with the model of large-scale coarsening-upwards sequence of several workers (Fisher et al, 1969) which records the transition from prodelta to shoreline lithofacies. Such sequences result from the progradation of the delta front, an area in which sediment laden fluvial currents enter the basin and are dispersed whilst interacting with basinal processes. In such a delta front, there is a general tendency for the coarse sediment to be deposited at the distributary mouth, whilst finer sediment is transported further into the basin.

The background sediments at the lower parts of the sub-association is regarded as the lower bar front facies or Distal Bar Deposit of many workers (cf. Flores, 1981). The evidence of its agitation based on the rippled siltstone lenses is usually considered to reflect the inception of wave base in this type of sequence (Elliott, 1978). The interbedded sandstone or siltstone and mudstone, remarkably well developed in Parkwood Quarry are considered to reflect the intermediate parts of the delta front, probably the intermediate depth mouth bars of some workers (Kelling & George 1971) and are interpreted as reflecting the interaction between sediment-laden incursions from the distributaries and deposition of sediment from suspension. Many beds of this intermediate depth mouth-bar have gradational bases which indicate increasing flow velocity and sediment transport upwards, probably related to a more gradual flood rise. The uppermost sand-dominated member exhibiting current-produced structures are regarded as the proximal delta-front deposits, probably proximal mouth bar, following Coleman (1976) and Elliott (1978). The dominance of Lithofacies 9 and 14, Parallel Laminated Sandstone and Horizontally Bedded Sandstone respectively, in the proximal part of the mouth bar area of this study is consistent with similar observation of several other workers in supposed mouth bar sediments (e.g. McCabe 1975, Casey 1980).

The channels associated with this sub-association may represent minor subaqueous extensions of the distributary down the delta slope. Scouring activity within the mouth-bar area is a normal phenomenon in a fluvial dominated delta front setting, during progressive shoreline progradation (Fisher and Brown, 1972). A modern analogue of this phenomenon is provided by the South Pass whose mouth bar crest, and to some extent the bar back, was eroded during the extreme river flood of 1973 whilst the bar-front prograded in a dune-like fashion (Elliott, 1978). The association of many of the erosive bases with flutes is suggestive of the strength of the current responsible for the channels. Equally suggestive of this strength are the common mud conglomerate lag deposits. Some of these channels may have been abruptly abandoned, for instance the upper two channels in Ramsden Clough, considering that their basal mudstone conglomerates are directly overlain by a mudstone unit which constitutes their only other infill sediments (cf. Leblanc, 1972). The lowermost channel in Ramsden Clough appear to have been abandoned comparatively slowly judging from their lithology.

Vertical displacement is speculated to be associated with the multi-directional dips in Ramsden Clough following a similar interpretation by Coleman _et al._ (1974). It is viewed that submerged diapirs which may be analogous to, if not, shale ridges may have deformed the units. Such diapirs are noted for modifying mouth bar sands of the Mississippi delta (Fisk, 1961; Morgan _et al._ 1968) substantially. Usually many such deformative features involving mass movements are associated with the escape of trapped over-pressured water and the development of a thixotropic condition in the sediment (cf. clay flowage, Elliott, 1978) possibly triggered off by a shale.

Relationship within the Delta Slope Association

Description

Even though substantial lateral variations characterise the Delta Slope Association of this study, as any groupings of the facies may occur, the following general trend appear identifiable.

The association is essentially a coarsening upward sequence with mudstones and siltstones dominating the lower parts while medium-grained to occasional coarse-grained sandstone dominate the upper parts. The Finer Lithofacies sub-association passes commonly upwards into the coarser Lithofacies sub-association. Channelized Lithofacies may occur within the main body of the Coarser Lithofacies Sub-association.

Interpretation

The Delta Slope Association is regarded as a coarsening upwards prodelta-mouth bar sequence. In comparison with similar, though much thicker sequences reported by Collinson (1967, 1969), and McCabe (1975) in R_1 times and by Baines (1977) in E_{1c} times in Central Pennine Basin, most of the slope sequence of this work appears to be shallow water in origin based on the thickness of the sequences (Fig. 12, 14-17). The mouth bar sands here are sheet-like in geometry and are usually substantially cut into by the distributary channel.

4.3. DELTA TOP ASSEMBLAGE

4.3.0. Definition and Introduction

Sediments described here are those thought to have been deposited in the extensive deltaic plain lowland areas developed behind the shoreline. Delta top areas of this work begin where the seaward sloping valley walls dip below the flood plain and are no longer confined by the river to a relatively narrow belt of the alluvial valley (Fig. 58). This surface is divided into two parts: the upper and the lower deltaic plains of several workers.

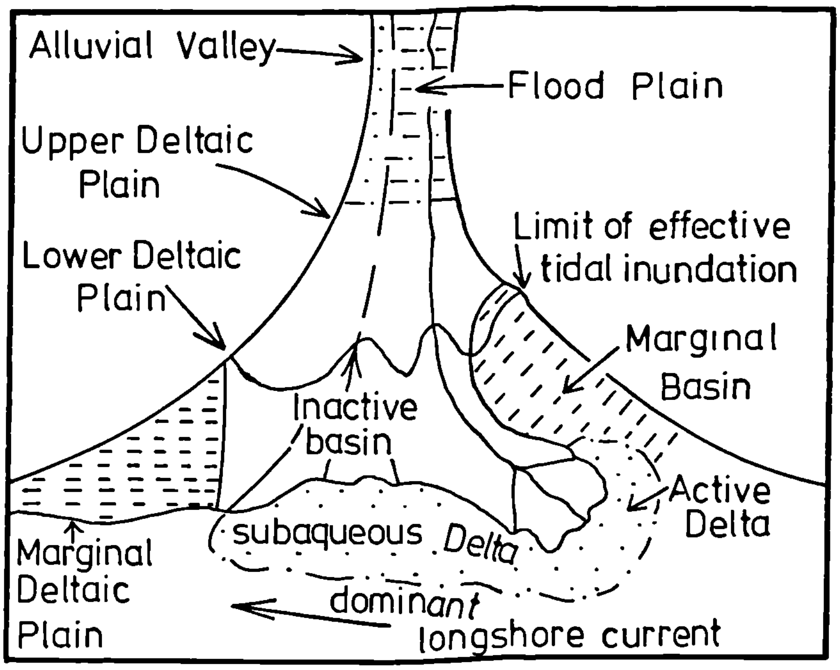


Fig. 58.
Delta Model indicating typical arrangement of major components.

The upper deltaic plain forms the apex with the alluvial valley, and at this apex the first downstream distributary may diverge. It is an area usually above the effective level of salt water intrusion and unaffected by marine processes. The lower deltaic plain lies seaward of the upper deltaic plain and is the zone which may be affected by marine processes, especially in deltas with high basinal energy.

The following three Associations are recognized within the Delta Top of the Middle Grits.

1. Distributary Channel Association
2. Interdistributary Complex Association
3. Abandonment Lithofacies Association

4.3.1. DISTRIBUTARY CHANNEL ASSOCIATION

Introduction

Two cross-sectional shapes of sand bodies characterise the channels of the association. These shapes range from lenticular concave-upwards based channel units to extensive planar-based rather sheet-like sandstones. Channels are considered as sheet-like when their planar erosional base can be traced in outcrop for hundreds of metres or when such lateral dimensions of the erosional surface can be inferred from field relationships,otherwise they are grouped with the lenticular based ones. The reason for this is that the bases of the lenticular types can locally appear to be planar. The possibility that some of the latter may after all be sheet-like is not ruled out, however, this grouping is done for ease of description. The channels of this association are therefore described under the following two loosely defined sub-associations which are fairly based on shape and extent of the exposed sand body.

(a) Major Channels Sub-association

(b) Sheet Channels Sub-association

4.3.1.1. MAJOR CHANNEL SUB-ASSOCIATION

Introduction

The sub-association includes all channels which are distinctively lenticular in geometry including the scour based sandbodies, discussed in section 3.13. and those other channels briefly commented on, in the introduction to section 4.3.1., which are not considered to be sheet-like. Channels here range in width commonly from 60m to some 800m and in thickness from 3m to some 30m as will be fully discussed below under the section on channel dimensions. Scour based sandbodies are included in the sub-association partly because of their individual shapes as discussed in section 4.3.1. but mainly because where the base of the thicker channel of which the facies is a component can be seen, such a base is often concave upward (Fig. 15, b, sequence 57-63m level). Also where the exposed base is too limited to portray the gross trough shape, the parts seen commonly lack the extensive planar nature characteristic of the sheet channels. Problems in categorization sometimes occur in such exposures of these small channels whose bases are not seen, like those at Riddlesden Quarry (SE 068430) and in Riverside Cemetary Quarry (SE 053237) both of which are in the Scotland Flags. In other words, in such cases it is not clear whether the small channels are part of a major channel or are distinct small channels whose dimensions compare with those noticed by Bluck and Kelling (1963) in the Basal Coal Measures of South Wales.

Channel Fills and Complexes

Channels of this sub-association are filled both by medium-grained sandstone and by coarse to very coarse-grained sandstone with pebbles. In those filled by medium-grained sand, the sediment sorting is generally good. In those filled by coarse-grained sandstone, the sorting is generally poor to very poor.

The lithofacies commonly occurring within these channels include the following: 17, Massive Sandstone; 14, Horizontal bedded sandstone; 12, Large scale Cross bedding; 13, Scour based sand bodies; 11, Tabular Cross bedded Sandstone; 10, Trough Cross Bedded Sandstone; 9, Parallel Laminated Sandstone; 6, Siltstone, commonly in striped form; 18, Pinch and Swell Sandstone; 1, Unfossiliferous Mudstone; 20, Seatearths and Coal.

Channels occur in complexes of up to 4 channels. Following Collinson (1967) a complex is defined as the recognizable channels delineated in a single vertical section or in lateral relationship in a large exposure. The number of erosion surfaces recognized in a complex is often a minimum value because of the narrow extent of most of the exposures containing the channels. For instance, at Fletcher Bank Quarry (SD 805165) where excellent cliff-face exposures over a horizontal distance of some 800m portrays the presence of 5 channels in the quarry (Fig. 59), vertical section at the northern parts of the quarry will indicate 4 channels because the fifth channel is restricted to the southern parts. With this definition, therefore the number and nature of only the prominent recognized channel complexes are shown in Tables 18 and 19.

Table 18. Number of Channels in Channel Complexes

Single	Channel	Complexes	20	giving	20	channels
Double	"	"	12	"	24	"
Treble	"	"	4	"	12	"
Quadruple	"	"	1	"	4	"
Total	"	"	37	"	60	"

Out of these 60 channels, 47 have their basal erosion surfaces exposed.

Dimensions of the Channels

The length of none of the channels is known. Tops of channels are often truncated by an overlying channel in a complex, or the top of the exposure corresponds with the top of the topographical feature. Also there is usually a limitation to the lateral extent of the channels due to lack of exposure. Rarely are both sides of a channel seen. Also, it is often difficult to ascertain the orientation of the channel in relation to the orientation of the exposure, this posing a problem to the estimation of the true channel width.

Out of all the exposures in the study area containing channels, Fletcher Bank Quarry provides the best opportunity for the study of the channels. It is a working quarry and significant sections of the 5 channels are exposed in 3 dimensions. Because of the detailed studies done in these channels and their associated bay fill sequences, the channels will be referred to several times for the illustration of several channel features. Also their vertical and lateral relationships plotted in Figure 59 and shown in Plate 102 will be referred to several times during the following discussions.

Great variability in thickness characterises the channels of this sub-association. The thickness of the channels at different stratigraphical levels, their grid references and their other vital features are shown in Table 19. As is clear from Table 19, and was also mentioned in the introduction above, these channels portray a thickness range of 3-30m, the small thickness constituting the Hazel Greave Grit of Gorpley Clough (SD 915235) while the 30m thick channel occurs at Owler Clough - Light Hazzles Quarry areas (SD 947195-948194). A possibility of amalgamation in this maximum thickness is not ruled out. The thickest channel fill whose measurement is regarded as reliable is that of Channel 1 of Fletcher Bank Quarry because both its base (Plates 101A & B) and top (Figs. 59 & 60, Plate 102) are well exposed. This channel has a maximum observed thickness of 29m. 31 out of the 60 channels have observed thickness above 8m. In fact out of the 31 channels with thicknesses above 8m, 24 have observed thickness of between 10m and 30m.

Out of the three chronostratigraphical intervals, the channels of Pule Hill Grit are generally thickest, coarsest in texture and greatest in number, while those of Hazel Greave Grit are commonly thinnest.

Out of these 60 prominent channels, it is only Channel 3 of Fletcher Bank Quarry that is exposed in complete cross-section. Not only are both its sides exposed, but also its orientation is known. Its orientation is based on the trend of the groove marks on its base. Its calculated width is 62m. Other channels show only one margin, such as the Northern margin of Fletcher Bank's Channel 2 (Fig. 60, Plate 102), or neither margin. In such cases only a minimum width can be estimated, and even then such estimation is possible only when the orientation of the channel is known. The greatest widths which can be inferred are those of Fletcher Bank's Channels 1 and 4, each of which is thought to be over 800m wide (they extend beyond the margins of the quarry). The width of Fletcher Banks Channel 5, which is thought to be over 90m, is based on the same evidence as in Fletcher Bank's Channels 1 and 4 mentioned above. These widths, cited here, are based on the lateral extent of their fills as observed in the main quarry face and so may not reflect true width, due to the possible oblique divergence between the orientation of the quarry face and the trend of the channels. Ponden Clough's Channels 1 and 2 are traceable over an outcrop width normal to palaeocurrent trend of over 70m. Based on the reconstructed morphology of Fletcher Bank's Channel 2, working from the geometry of, and the lateral extent of, the exposed margin and parts of the channels, the estimated width is 240m. The other inferred minimum widths of the other major channels tabulated in Plate 19, commonly range from 50-600m.

Erosion Surfaces of the Channels

Channels are cut either into the interdistributary Complex Association or into the sandstone fill of an underlying Channel where they occur in complexes, or even intc sediments of the slope association. Two types of relief, namely large scale relief associated with the geometry of the channel as a whole, and a small scale relief, which is the measured relief of scour, are recognized. Channel cross sections where they can be recognized, or reconstructed as in Channel 1 of Fletcher Bank Quarry (Fig. 60) are often concave upward, though flat based Channels occur also. The channel margins commonly slope at between 15 and 35^{o}, though margins as low as 5^{o} occur at the northern margin of Channel 2 of Fletcher Bank Quarry. Channel cross section may be asymmetrical as shown by Channel 3 of Fletcher Bank (Plate 102, Fig. 60), where the northern side is steeper than the southern side.

Minor relief on erosion surfaces of channels varies from small grooves as at Fletcher Bank Channels 2 & 3 or Park Wood Quarry (SE 067406), to flutes as at Cowloughton Clough (SD 965413) Diggley Quarry (SE 110074) to even more intensive irregularities. Groove and flutes are often the only evidence of channel orientation. In the Central Vertical Section area of the Fletcher Bank Quarry (Fig. 59), where the scour base of

Channel 1 is prominent (Plate 101B), the measured relief of scour is 3.25m, and the sandstone units of the underlying bay fill sequence are eroded down to the top of the 1m thick trough cross laminated sandstone directly overlying the bay mudstone. Also in Fletcher Bank, deeper scouring of the mouth bar deposits, comparable to the model of the high constructive delta of Brown (1973), occurs locally (Plate 101A). In such places, relief of scour is up to 6m. In Gorpley Clough, the Pule Hill Grit Channel which is 23m thick erodes into the mouth sediments (50m level. sequence g, Fig. 16) and the measured relief of scour is over 2.5m. Also the measured relief of scour on the Hazel Greave Channel in Gorpley Clough is some 4m. More intense local irregularity may produce steep steps on erosion surfaces. A good example of this is demonstrated by Channel 4 of Fletcher Bank Quarry (Fig. 59, Plate 103) where the base which is sharp, horizontal and prominently flat for some 180m. Moving northwards from the southern end of the quarry, this surface scours a depth of 3.7m steeply into the underlying bay sediments consisting essentially of the following lithofacies: 1, Unfossiliferous Mudstone; 5, Mudstones and Siltstones; 6, Siltstones; 7, Rippled silty sandstone; 8, Trough Cross Laminated Sandstone. Further details of these lithofacies are given in section 4.3.2. concerned with Interdistributary Complex Association. From this locality to the northern part of the quarry, this erosive base undulates irregularly, though never rising to its former (southern) level.

There is no obvious indication that the nature of the substrate has any direct relationship with or influence on the relief of the erosion surfaces. At Fletcher Bank Quarry for instance, both Channels 1 and 4 appear to have excavated substantial scours irrespective of the different nature of their substrates. Indeed, the difference in the obvserved maximum relief of scouring in Fletcher Bank's Channel 1 (6m) and 4 (3.7m) appears to relate more to the overall depths of the channel than to the substrate nature as was noted by Okolo (1982, in press).

Channel Fill Sequences and Lithofacies Relationships

The vertical order of the channel fill sequence within the channels are shown in Table 19. The erosional surfaces indicated in this Table are commonly marked by lag concentrates often composed of abundant plant fragments (Plate 87B) sometimes logs of wood (Plate 43), pebbles (Plate 87A & D) mud conglomerates (Plate 87C). Large blocks of sandstones and siltstones characterise the erosional bases seen in Ponden Clough (SD 980364), Fletcher Bank Channel 4 and Hanging Stone Quarry (SE 044200), Ripponden. Apart from the erosional bases, plant fragments (sometimes coalified), occur within the channel fills and this has been noted in Chapter 3, under the respective lithofacies that they occur in. From Table 19, it can be seen that whenever massive units exist within the channels, they generally occur immediately above the erosive base. The transition from the massive units to other lithofacies takes a variety of forms. However, it is obvious also from Table 19 that whenever Lithofacies 12, Large Scale Cross bedding occurs together with lithofacies 10, Trough Cross Bedded Sandstone or Lithofacies 11, Tabular Cross Bedded Sandstone the Large Scale Cross Bedding commonly underlies any of them. Apart from existing at various levels within the channel, though more often at the upper parts (Fig. 59), Lithofacies 5, Mudstones and Siltstones or 8, Trough Cross Laminated Sandstone commonly occurs in some of the internal erosion surfaces particularly of Lithofacies 12, Large Scale Cross Bedded Sandstone.

Table 19. Features of the Distributary Channels

	Location of Channel	National Grid Reference of Channel	Number of Channels in Complex	Channel Thickness (M)	Vertical order of Lithofacies Expressed in Lithofacies Number Notation	Probable Channel Type
Scotland Flags	Riddlesdon Quarry	SE 068430	3	9.7	13 (10 INT)	Scour based
	Diggley Quarry	SE 110074	1	18.5	12→14 & 12	Major
	Riverside Cemetary Quarry. Channel 2	SE 053237	2	7	E→11	Major
	" " " " 1	SE 053237		>8	13	Scour based
	Castle Carr Quarry	SE 028301	1	10	E→10	Sheet
	Triangle Railway Cutting	SE 047224	1	19	12 & 11	Major
	Red Lane Dike	SE 062175	1	5	E→17	Major
	Bare Clough	SE 019309	1	5	E→10	Major
Pule Hill Grit	Pule Hill. Channel 3	SE 032105	3	4-11.6	E→13 (10 INT)	Scour based
	" " " 2	SE 032105		>4	E→13 (10 INT)	" "
	" " " 1	SE 032105		>4	13 (10 INT)	" "
	Rake Dike	SE 100052	1	9	E→10	Major
	Bare Clough. Channel 2	SE 018309	3	6.2	E→17	Sheet
	" " " 1	SE 018309		10	E→17	"
	" " " 1A	SE 018309		5	E→10	"
	Red Lane Dike	SE 061171	1	14	E→10	"
	Braithwaite Quarry. Channel 2	SE 040418	2	8.70	E→10	"
	" " " 1	SE 040418		>5.20	E→10	"
	Bronshaw Quarry	SE 031402	1	4	E→17	"
	Woodhouse Quarry. Channel 2	SE 062397	2	6.5	E→11	"
	" " " 1	SE 062397	2	6.0	E→10	"
	Wicking Crag Quarry. Channel 2	SE 049374	2	10	E→12→20	"
	" " " " 1	SE 049374	2	13	E→10→16→10	Major
	Ponden Clough. Channel 2	SD 980364	2	12.48	E→17→10	"
	" " " 1	SD 980364	2	10.80	E→10	"
	Buckden Clough. Channel 2	SD 789188	2	>23	E→10→14	"
	" " " 1	SD 789188		21.40	E→17→11→8	"
	Fletcher Bank Quarry. Channel 5	SD 805165	4	3.6	E→10→20	"
	" " " " 4	SD 805165		11	E→10→14→6	"
	" " " " 3	SD 805165		5	E→14 & 12→8→20	"
	" " " " 2	SD 805165			E→10→1→9→10→6	"
	" " " " 1	SD 805165		29	E→14→12→11→10→8	"
	Tower Hill Side	SD 906261	1	22.50	12→10	"
	Gorpley Clough	SD 915235	1	22.80	E→10	"
	Owler Clough. Channel 2	SD 947196	2	10	10→8→11	"
	" " " 1	SD 947196		30	17→10	"
	Erwel Bank	SD 789195	1	11	17→10	"
	Chatterton Wood	SD 794188	1	10.50	E→17→11→10	"
	Readyshore Scout. Channel 3	SD 942198	3	6.2	E→10	Sheet
	" " " 2	SD 942198		5.8	E→11	"
	" " " 1	SD 942198		6.4	11	"
	Sabden Clough	SD 746341	1	>13.50	E→17	?Major
	Swinden Clough	SD 910330	1	?>3	E→17	Major
	Cowloughton Clough. Channel 3	SD 965413	3	3.70	E→10→11	?Major
	" " " 2	SD 965414		?35.66	E→10→11→10→11→20	"
	" " " 1	SD 965414		6.60	E→10	"
	Warland Wood Quarry	SD 948202	1	20.20	12→10	?Major
	Hanging Stone Quarry	SE 044200	1	20	E→17→10	Major
	Kebroyd Quarry. Channel 3	SE 040210	3	4	E→10	"
	" " " 2	SE 040210		3	E→12	"
	" " " 1	SE 040210		6	10	"
Hazel Greave Grit	Wicking Crag Quarry	SE 052372	1	6	13(10 INT)	Scour based
	Bracken End. Channel 2	SE 194433	2	11.20	11	Sheet
	" " " 1	SE 194433		4	17→11	"
	Carlton Moor Quarry. Channel 2	SE 199431	2	5	17→10	"
	" " " " 1	SE 199431		4	10	"
	Eshott Junction Railway Cutting	SE 193413	1	8	12→11	"
	Tower Hill Side. Channel 2	SD 906261	2	6.56	E→10	Major
	" " " " 1	SD 906261		4.60	E→13→20	Scour based
	Gorpley Clough	SD 914234	1	3	E→13 (10 INT) →20	" "
	Swinden Clough	SD 910330	1	7.50	17→11	Major
	Scout End Quarry	SD 788194	1	5.50	E→17	Sheet

E = Erosion surface where exposed

CH = Channel

13(10 INT) = Trough Cross Bedded Sandstone is an intraset in Scour Based Sand Bodies

Arrow shows upwards order

In addition to the vertical lithofacies changes shown in Table 19 it is necessary to also consider lateral lithofacies variations. Good examples of the latter occur in Diggley Quarry (SE 110074) in Holmbridge area and in Channel 3 of Fletcher Bank Quarry (Fig. 60). In the latter, the upper parts of a solitary set of tangential foresets of Lithofacies 12 Large Scale Cross Bedding which forms virtually the whole in-channel deposits, grades to Lithofacies 14, Horizontal Bedded Sandstone when traced northerly.

Both the cross beds and the horizontal beds also grade vertically to a thin unit of lithofacies 8, Trough Cross Laminated Sandstone (Table 19) which is very rich in in-situ Stigmaria and rootlets (Plates 96 & 97) and logs of wood. In addition to grading northwestwards to horizontal beds , the solitary set of tangential foresets also appears to be oriented obliquely to the channel margin and the main palaeocurrent trend (Fig.60) as will be substantiated during its next discussion in the following section. In Diggley Quarry, Lithofacies 14, Horizontal bedded sandstone grades southeastwards (that is obliquely to downcurrent direction) to Large Scale Cross Bedding as was discussed in section 3.12.1. and further expatiated on in the following section dealing with Palaeocurrents and Mechanisms of Erosion, Channel filling and Abandonment. Other striking lithofacies relationships that need to be emphasised here are as follows:

(a) The presence of a series of parallel set boundaries gently dipping at 4-8^{0} that banks against the northern margin of Fletcher Bank's Channel 2 (Plate 102, Fig. 60), in a direction roughly perpendicular to the true palaeocurrent trend (12-17m level, southern vertical section, Fig. 59). This relationship is discussed further in the following section.

(b) The large scale sigmoidal foresets in the Pule Hill Grit in Kebroyd Quarry already discussed in section 3.12.1.

(c) The downcurrent gradation of cosets of medium scale cross beds into sets of Lithofacies 12, Large Scale Cross Beds that occurs in the Pule Hill Grit of Ramsden Clough whose spatial lithofacies relationships are shown in Figures 43-46 and summarised in Figures 65A & B.

(d) The co-existence of sets of Lithofacies 11 and 12, Tabular Cross Bedded Sandstone and Large Scale Cross Bedding in some localities particularly in Triangle Railway Cutting (SE 049224) and Hanging Stone Quarry (SE 044200) Ripponden. In Triangle, both cross beds whose set thickness commonly ranges from 0.20-0.50m and those of 2.4m can occur in a coset. Set thicknesses of 1-2m are generally scarce and so sets of 2-4m are prominent in the coset. Consequently, the choice of 2m as the set size-limit is arbitrary because it is regarded as a reasonable approximation to the general natural limit in the study area between the two magnitudes.

(e) The numerous internal erosion surfaces which truncate their underlying large scale foresets as already discussed in sections 3.12.1. and 3.13.1.

(f) Intrasets of Trough Cross Bedded Sandstone commonly seen in large scale foresets as also discussed in sections 3.12.1. and 3.13.1. The current responsible for the intrasets discussed in section 3.13.1. which occur in Pule Hill Quarry and plotted in Figure 51 appear to have moved in a direction parallel to the strike of their associated large scale foreset.

Palaeocurrents and Mechanisms of Erosion, Channel Filling and Abandonment

Palaeocurrents. The orientations of groove marks measured from the channels' lower boundaries (Plate 104) or from the boundary of the channel's infill unit are considered as reliable trends of the channels. They are preferred to the internal direction from the fills, following Allen (1966) who demonstrated progressively greater current directional variability with decreasing size of bedform. The critical features of the grooves which recommend them as such good current trend indicators are their long, remarkably linear course indicating the locus of the tool that generated it. However, in their absence, other moving tool marks particularly prod marks have been used. Scour marks, especially flutes but also longitudinal furrows and ridges have been used where found. Palaeocurrents were also obtained from the primary current lineation of lithofacies 9, Parallel Laminated Sandstone. Even though the details of these directional data are reserved for Chapter 6, the direction from some cross bedding infill are discussed below in relationship to their associated channels treated in the paragraph dealing on channel filling mechanisms.

Erosion. Traction currents are regarded as the cutting mechanism of the major channels of this study, based particularly on the sedimentological context of the channels. These currents must have possessed strong erosive power to be able to cut channels as deep as is shown in Table 19. The significant relief of scours on the base of many of these channels, particularly channels 1 (6m), 3 (3m) and 4 (3.7m) of Fletcher Bank Quarry (SD 805165) or channels 1 (over 2.5m) and 2 (4m) of Gorpley Clough are indicative of the erosive power of these currents. Further evidence of this strength is provided by the fact that in many cases, the material eroded is of fine grain size which is often more difficult to erode

(Sundborg, 1956). The coarse, pebbly texture of channel fills of several of these channels suggests that such material might have considerably added to the abrasive power of the stream. The fact that channel walls are locally very steep (cf. Fletcher Bank Channel 4) suggests that the eroded sediments had achieved considerable strength due presumably to compaction under a thick cover of sediment, equal in thickness to the channel depth. Also,since the fine sediment of the interdistributary complex association (see section 4.3.2.) accumulated relatively slowly, there was probably a considerable interval of time available for the compaction. The presence of large blocks of siltstone in the lower parts of many of the channels particularly Channel 4 of Fletcher Bank Quarry and the Hanging Stone Quarry, Ripponden (SE 044200), provides an additional indication of the strength of the eroded sediments. Together with mudclasts, these siltstone lags indicate further that at least some of them (that is, mudclasts and siltstones) were eroded as blocks probably due to their relative ease of doing so compared with grain by grain erosion. It is conceivable therefore to imagine that most of the eroded sediments were removed in this way. The general absence of a mudstone unit between the erosive base and the infill sediments (Table 19), suggests that the same currents cut and filled the channels, either contemporaneously or shortly afterwards.

Since it is widely accepted that the maximum competency of a stream is associated with its erosive surface, the general impression one gets from the lithofacies vertical transition shown in Table 19 is that of lithofacies deposition from a waning flow.

Channel Filling and Abandonment. Two mechanisms of channel filling appear dominant. These are side- and vertical-filling using the terminology of Bluck and Kelling (1963). The mechanism of each channel-filling was deduced particularly from the arrangement of the sediments within the channels, and also from the geometry of the channel margin. Where the shapes of the channel margins and fills are conspicuous as channels 2 and 3 of Fletcher Bank, the interpretation of the method of fill is much easier. Difficulties usually arise because of insufficient exposure, lack of specific evidence and the complexity of the fill especially when it comprises a mixture of materials derived by more than one method. The mechanisms of channel fill appear to be related to different modes of channel abandonment as is discussed below.

i. Vertical sedimentation is considered the dominant channel filling mechanisms for most of the channels in the study area as is illustrated by channel 1 of Fletcher Bank Quarry (Fig. 59). Shallowing accompanied by upward decreasing flow strength are reflected in both the vertical reduction in the set thickness of the cross-beds and the progressive vertical transition to other sedimentary structures of lower energy level in this channel. Such upward reduction is explainable in the context of a vertical filling, even though contribution by lateral migration is not ruled out. Also the concave upward base of the channel and the horizontal geometry of the set boundaries within it (Okolo, 1982, in press; Fig. 60) are usually attributed to vertical accretion (Kelling 1968; Bluck and Kelling 1963). Therefore, even though conclusive evidence is lacking due to absence of definitive channel margins, the evidence provided above by channel-fill lithology and geometry and also the geometry of the channel base argue in favour of a vertical fill. Abandonment of this channel might have proceeded in a slow manner based on the gradual upward waning of flow strength. Such a slow process might suggest that a shorter and steeper alternative younger channel could develop and take over the discharge of the channel until it is finally abandoned as in the case of the present-day Atchafalaya (Gould, 1970).

ii. The side-filling mechanism considered to be responsible for the filling of other channels not filled by vertical accretion is thought to have occurred because of accretion on the flanks of alternate bars as is illustrated by Figure 61, a postulated model for the infilling of channel 3 of Fletcher Bank Quarry. In this channel 3 for instance such an accretion is thought to have generated the tangentially based foresets (Figs. 60 & 62) occurring within as discussed below, based on palaeocurrent evidence (Figures 63A & C). Flow in the lower part of the upper flow regime moving over the surface of the alternate bars is thought to be capable of generating flat beds over the top surface of the alternate bars. This sediment can avalanche down the flank of the downstream slip faces into the inner part of the channel as is suggested by YY^1 in Figure 61. Such flows are possible during flood. The model assumes that both the Horizontal Beds and the cross-beds are in-channel deposits, and so contrasts with the Bijou Creek of McKee, Crosby & Berryhill (1967) in which the Horizontal beds are thought to represent the sand spread out beyond the channel.

Although the palaeocurrent directions indicated by the foreset dips within the channel (Fig. 63A), and the plants (Fig. 63B) and ripples (Fig. 63C) on top of the channel, are fairly consistent, they are slightly oblique to the channel trend. Thus, even though components of the inflowing current towards the leeside surface may have contributed (Fig.63B) in the infilling of channel 3, they have not contributed as much as those at the flanks. This directional anomaly is explicable in the context of side filling.

Fig. 62.

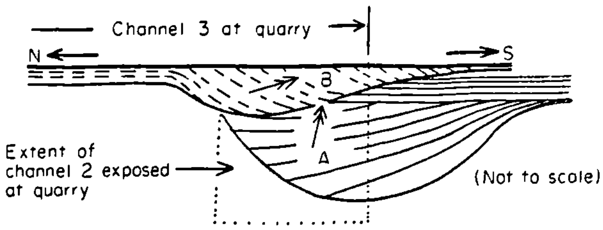


Fig. 62 Sketch diagram illustrating channels 2 and 3 fill geometry, and their cross-cutting relationship. Palaeoflow is indicated by double arrow. (A) Channel 2, filled asymmetrically by inclined strata generated by currents moving in a direction oblique to channel 2 axis (after McKee, 1957). (B) Channel 3, filled asymmetrically by tangentially based foresets deposited at the flank of alternate bar. Note the northwards gradation of tangential cross-beds to horizontal beds. From Okolo (1982)

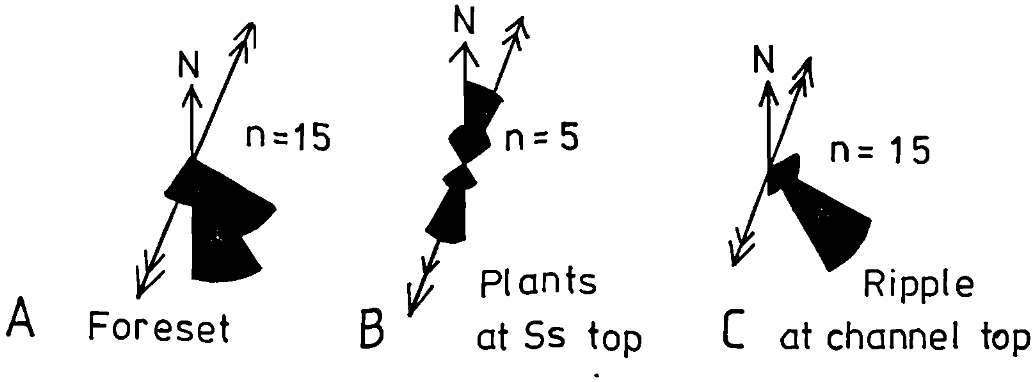


Fig. 63.

Palaeocurrent Histogram for Fletcher Bank Channel 3.

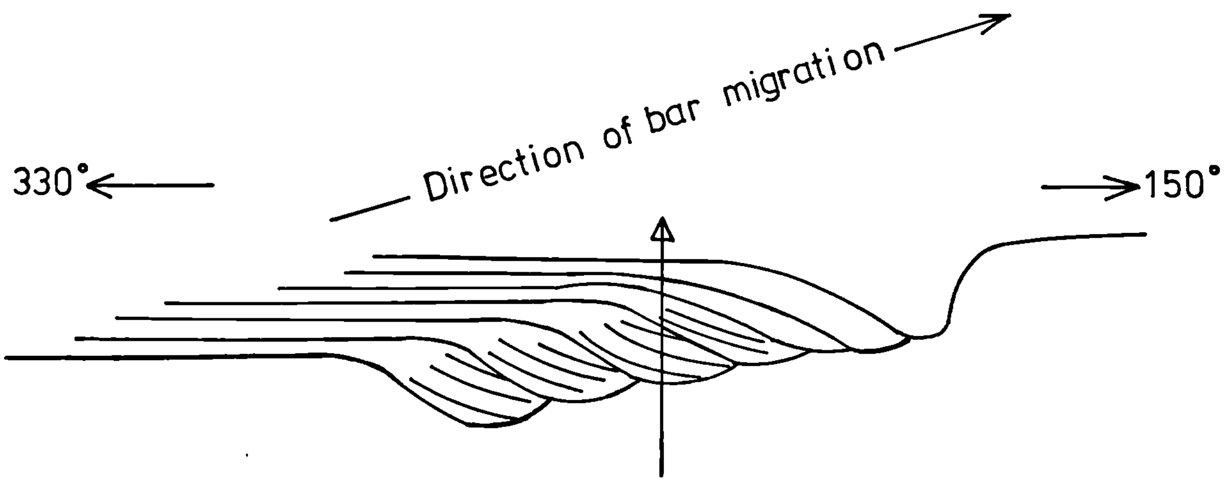
/‾A_7 Foreset dip direction within the Channel. /‾B_7 Plants on top of Channel 3c. Ripple flow direction on top of Channel 3.

The northwards gradation of the upper parts of tangential foresets to Lithofacies 14, Horizontal beds is also explicable in the context of the type of alternate bar model suggested in Figure 61.

In the case of the Diggley Quarry (Fig. 42) whose infill model is represented by Figure 64, it appears that during the subsequent downstream

Fig. 64.

Model of Channel Filling in Diggley Quarry.



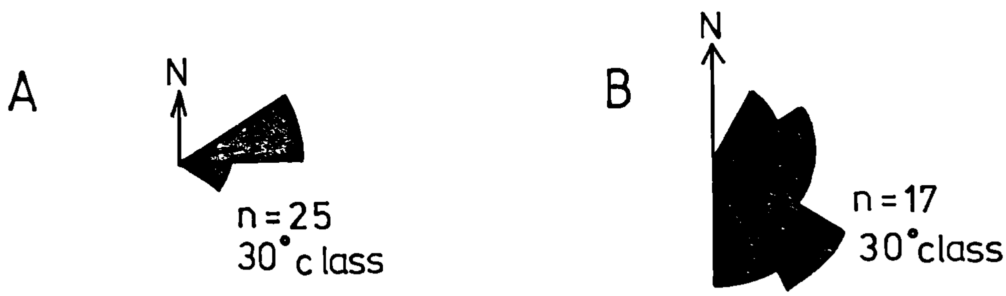


Fig. 65.

Directional data in Diggley Quarry.

A. Flutes at base of Erosional Surface (1) of Fig. 42.

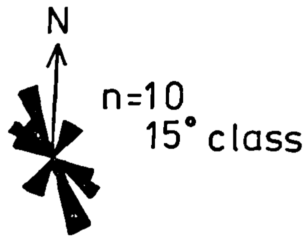
B. Foreset dip direction.

migration of the slip face, the channel progressively cuts its own deposit, thereby causing the Horizontal beds of a higher bed to lie on the inclined

Fig. 65.

Directional data in Diggley Quarry.

C. Pelecypodichnus "Bumps" Orientation.

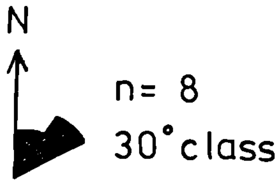


part of a lower one. It must be emphasised that in this model, the inclined units are considered as a large scale foreset at the flank of the alternate bars downstream slip face, based on palaeocurrent data (Figures 65A, B & C) and are not thought to be due to lateral accretion of point-bars. Several authors have reported large scale cross beds (their sigmoidal beds) in ancient fluvial sandstone units (Jackson, 1978) and have usually referred to them as epsilon cross stratification which they frequently attribute to point bars. The shortcomings of such generalized point bar interpretation have been discussed by Jackson (1978). The best modern analogue for the river that deposited these sediments may be relatively straight rivers (low-sinuosity rivers) with alternate bars. Describing a comparable low-sinuosity river Nedeco (1959) talked of a "reach" type, flowing in its own alluvial sediment .... the thalweg winding between essentially straight river banks".

The major difference in the infill models envisaged for Diggley Quarry and Fletcher Bank's Channel 3 is that only one set of foresets thought to have resulted from a single episode of flood sedimentation is involved in Channel 3. As regards the abandonment of Channel 3, it is thought that the channel may have been a relatively short-lived feature, because based on its thickness, its initiation might have immediately preceeded its abandonment. Such an abandonment may have resulted due to an upstream switching of a fluvial channel which supplied it. Also the proximity of the coal capping the sequence of Channel 3 to the base suggests an abandonment of the entire delta lobe which it feeds (Elliott, 1976). The coal bed lies on a well developed rootlet-rich upper part of Channel 3.

iii. The only side filling mechanism not thought to follow the model of Channel 3 or Diggley Quarry infilling is that responsible for the deposit in Channel 2 of Fletcher Bank. Here the inclined relationship of the series of parallel set boundaries to the northern margin of Channel 2 (Plate 102, Fig. 60) partly discussed above, indicates a side filling mechanism, but the side-filling process by "Abandonment stage currents", of the form described below is envisages as the probable dominant filling mechanism.

"Abandonment stage Current" deposition. During the abandonment of the channel, traction currents probably moved in a direction oblique to the axis of the channel (Fig. 67). This oblique movement might have been associated with reduction in stream depth and velocity as indicated by the upward decrease in grain size and set thickness of the trough cross bedding.



Deposition resulting from such a waning flow side movement is capable of generating strata that bank at gentle angle to the channel margin (Figs. 60 & 67). A combination of side filling and vertical accretion of this form progressively reduces the cross-sectional area of the channel. Its uppermost striped siltstone (Fig. 59) is probably spread across its whole upper surface as is indicated by its tabular geometry. The side-filling method envisaged here and whose postulated model is sketched in Figure 62 is similar to the type responsible for the "asymmetrically filled channel" of McKee (1957). Reineck and Singh (1975) contend that "when intertidal flats are still under water, and flow of water is controlled more by difference in water levels than the surface morphology", such asymmetrical filling of channels commonly occur. Tidal activity is however not envisaged for these channels particularly because of absence of current reversals. Similar side filled channels were reported by Bluck and Kelling (1963) in the basal Coal Measures of South Wales.

Abandonment of Channel 2 must have been slow to have allowed the gradual upward decrease in grain size and set thickness and even to be capped by striped siltstone which probably represents infilling by diminished flow.

Genesis of the Massive Sandstone and Large Scale Cross Bedding

MASSIVE SANDSTONE. The possible formative mechanism for the massive sandstone, Lithofacies 17, has been partly discussed in section 3.17.2. Added to these mechanisms is the antidune formative model postulated by Collinson (1967). While it is easily conceivable that massive beds can form by any of these processes in the channels where it is the only infill lithofacies, it is felt that freezing of a traction carpet,or non-turbulent sediment gravity flow may probably not occur at the bottom of a river with large or medium scale bedforms,except if the deposited massive bed is in a metastable state. This view is held because it is felt that, under normal conditions, the transition from the massive beds into cross-beds suggests a process-related phenomenon, and if so it is hard to conceive that these two bedform states (that is, massive at the base and cross-beds at the top) can be in equilibrium with the flow at the same time. Such an association rather represents different responses to different discharges, and in such a case one should expect an indication of abrupt change in depositional condition often represented by a bedding plane. Such a distinct plane does not occur.

It is therefore felt that most of the Marsdenian stage Massive Sandstones probably represent any or a combination of the following processes.

(i) Trough deposit of large bedforms as proposed by McCabe (1975). He contends that since the reattachment point of a flow over a bedform is an area of erosion, with sediments being transported both away and towards the slip face, the possibility of organized lamination forming under such a chaotic situation is consequently low particularly in very coarse to pebbly sandstone.

(ii) Products of scour troughs incized at the basal parts of a slip face of a large bedform as suggested by Rust (Personal Comm., September 1981, see section 3.17.12).

(iii) Deposition in certain upper flow regime conditions as postulated by Walker (1965) and Harms & Fahnestock (1965).

(iv) Antidune deposits postulated by Collinson (1967) and further suggested by Conaghan and Jones (1975).

The last theory has a major disadvantage, as it will be very curious to have antidunes at the foot of big slip face, which is what might have occurred for the sandstone, and its overlying large scale cross beds. Based particularly on the vertical lithofacies relationships, the author prefers the first two theories listed above as the most possible mechanisms that generated the majority (if not all) the massive beds of this association.

LARGE SCALE CROSS BEDDING. The several theories advanced to explain its genesis have been mentioned in section 3.12.2. The 4 models proposed by McCabe (1975) also mentioned in section 3.12.2. are presented in an annotated form consisting of models A, B, C, D (Fig. 69).

McCabe (1975) contends that models A, Channel Confluence delta and B, Channel Infill delta were too localized in extent and as such would not account for the widespread occurrence of the large scale cross bedding in the R_1 succession. He considers models C and D as more applicable. Even though this opinion is accepted in the light of the evidence in the R_2 sequence as is discussed below, it is felt that the Channel Confluence delta model might have contributed locally in the fills of the Pule Hill Grit in Pule Hill area (SE 032105) based on the palaeocurrent evidence (Fig. 51).

Alternate Bar Model. The alternate bar model of McCabe (1975) which assumes that the large scale bedforms were alternate bars is considered responsible for the majority of the large scale cross beds of this sub-association, based on the factors that will be discussed below. Alternate bars are common in straight channels (Leopold & Wolman, 1957), and the best documented alternate bars are those from the Rio Grande described by Harms & Fahnestock (1965) where downstream of the crest line, there is an avalanche face generating tabular cross-beds. Some of the factors that recommend alternate bars are as follows.

1. The oblique relationship of the large scale cross beds to their channel axis especially Fletcher Bank Channel 3 discussed above and the sigmoidal foresets at Kebroyd Quarry. Also the close proximity of some large scale cross-beds, particularly at Fletcher Bank Channel 3, to the Channel margins, suggests bar attached rather than mid-channel bed form.

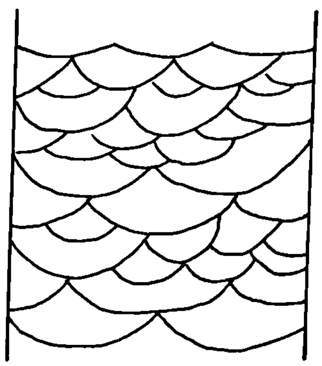
2. Preservation of large sets is more likely for alternate bars than sandwaves as its preservation can take place by channel migration as well as channel abandonment (McCabe, 1975).

3. Alternate bar model accounts also for the presence of internal erosion surfaces in lithofacies 12, Large Scale Cross Beds. This is because alternate bars are often eroded during low and falling stage discharge when the thalweg sinuosity reduces its wavelength to correspond to the lower discharge (Fig. 71). The erosional activity mechanism here may be loosely analogous to the process postulated by Collinson (1970) for the generation of internal erosion surface in the cross stratification of the linguoid bars in Tana River. In the latter both wave action and the current flowing round the abandonned bar, rounded off the top of the avalanche face which was subsequently reactivated at the next flood.

The other two possible models for the generation of the large scale cross beds proposed by McCabe (1975) and thought to be likely by the writer are discussed below:

Sandwave Model. This postulates (Fig. 69) that the bedforms which generated Lithofacies 12, Large Scale Cross Bedding were large sandwaves such as those described by Coleman (1969) from the Brahmaputra. In other words the bedforms were similar to those that generated the medium scale cross beds except that in the case of lithofacies 12, they were larger, possibly developed at peak discharges. The advantage of this model is its ability to explain the prevailing natural continuum in scale between the cross bedding types seen at several localities, particularly at Triangle Railway Cutting and Hanging Stone Quarry, Ripponden, where sets of both medium scale cross beds co-exist in one coset as described above. The type of the co-existence of these different scales as seen at Hanging Stone Quarry, is sketched in Figure 70, the relationship of which is

Fig. 70.
Coset of Medium Scale and Large Scale Cross Beds in Hanging Stone Quarry, Rippenden.



Not drawn to scale.

explainable in the context of the co-existence of two similar types of bedforms developed at different discharges. In short, the sandwave model may be the producer of some of the large scale cross beds seen at some of the localities.

The presence of Lithofacies 8, Trough Cross Laminated Sandy Mudstone within the gap (AB, Fig. 42), regarded as a reactivation surface in Diggley Quarry suggests that at least it was formed by low stage modification of a large bedform. Fluctuating discharges may also exercise influence on the type of foresets generated. Thus, it is felt that types 1 to 3 foresets described in section 3.12.1. may have developed at different discharges as is suggested by Figure 72, or at different positions of bar crest, or due to a combination of both. The envisaged processes involved in the generation of these internal erosion surfaces and the types 1 and 2 foresets particularly in Diggley Quarry are summarized in Figure 73.

4. McCabe & Jones (1977) reported also the formation of reactivation surfaces due to the arrival of ripples at the "delta crest" of a two dimensional delta which they built in a flume at Keele University. In other words, smaller bedforms on the back of the larger bedform or in channel feeding deltas could form reactivation surfaces in the upper part of the large scale cross bed set.

5. The presence of medium scale cross bedded sets passing downstream into large-scale sets is indicative of the existence of superimposed smaller bedforms on the back of the larger bedform, a phenomenon presently widely recognized on side and alternate bars (cf. Collinson, 1978). The medium scale cross bedded units are considered to represent smaller bedforms such as dunes, bars and scour infills, often developed in the shallower parts of rivers.

Since large scale cross beds do not occur in some parts of some channels the following suggestions modified from McCabe (1975) and Jones (1977), appear to the author as reasonable explanations of the spatial relationships of the large scale cross beds to medium scale cross beds.

a. While alternate bars are often restricted to narrow deep channels in low sinuosity river, the smaller bedforms are reported largely from wider shallow areas. A modern analogue of this relationship is the Niger (Nedeco 1959) where the best development of the side bars occur in narrower channels. The superimposition of the smaller bedform on top of the alternate bar can result during lateral migration of the shallow parts of the channels.

b. Smaller bedforms are superimposed on the backs of alternate bars formed on opposite sides of a straight channel, and also upstream in areas where the thalweg crosses over from one side of the channel to the other (Fig. 71). Consequently, in places in the channel where only small bedforms occur, cosets of the medium scale cross beds form whereas in other areas sets of lithofacies 12, Large Scale Cross Beds are overlain by cosets of the Medium Scale Cross Beds reflecting the superimposition of bedforms.

It must be emphasised however, that not all channels necessarily developed alternate bars, because where the discharge was not great enough channel fills will be dominated by cosets of Trough Cross Bedded Sandstone or Tabular Cross Bedded Sandstone.

Interpretations and Summary

1. Major channels are essentially lenticular in cross section when they are fully exposed.

2. Major channels occur in complexes of up to 4, with common thickness range of 3-30m. Sometimes some of the thicker channels may be made up of smaller sized channels called scour based sand bodies. The presence of such internal channels suggest that flows fluctuated considerably.

Based on geometry, size, presence of lag concentrates, as discussed in section 3.13.1. and various fill geometries also described in 3.13.1, the scour based sandbodies are considered as low sinuosity channels within a larger sized low sinuosity tract (probably a braided tract). The dimensions of many of these scour based sandstones falls within the lower size range of many channels of Westwater Canyon Member of the Morrison Formation of New Mexico described by Campbell (1976) which he interpreted in a similar way.

3. Channel fill successions are thought to be net products of the waning of the maximum flow regimes developed by the highest flood as in Brahmaputra (Coleman, 1969).

The following reasons suggested by Collinson (1967) and accepted by the author are considered capable of causing the initiation of channel down-cutting and a subsequent filling by a waning flow.

(i) "Diversion of a large river, either suddenly or gradually, followed by a gradual cutting off of its own supply.

(ii) Climatic changes giving increased run-off which subsequently waned.

(iii) Relative fall and subsequent rise in basin level, giving increased slope and therefore erosion by aggradation".

4. Side and/or Vertical Filling Mechanisms are thought to have operated during the infilling of the channels.

5. Most of the massive beds are thought to be trough deposits of large bed forms, or products of scour troughs incised at the basal parts of a slip face of a large bed form.

6. The large scale cross beds are thought to be products of alternate bars developed in the narrow deep parts of rivers of low sinuosity.

Deformational Structures and their Interpretations

The deformation structure within lithofacies 11, Tabular Cross Bedded Sandstone at Riverside Cemetary Quarry, Sowerby Bridge, within this association has been discussed in section 3.11.3.1. Another prominent structure within this sub-association with a similar scale to the Sowerby Bridge structure occurs at Wicking Crag Quarry (SE 049374), a cliff-face roadside exposure located 4 miles southwest of Keighley.

Here, 3 principal and 9 small normal faults are recognized within a unit of lithofacies 13, Scour based sand bodies. The major fault (Y-Y') which has a downthrow of some 4m and a horizontal extent of some 75m is wide and curved in plan, being concave towards the northeast (that is, towards the road, Fig. 74). The width of the major fault's zone is 2m and it is occupied by a muddy unit. Brecciation is prominent in the strata adjacent to the fault plane of ZZ' in the southeast part. Here, the broken mass of angular rock fragments masks the sedimentary structures. The brecciated zone is also prominently white due to weathering. The exposed downthrown strata range in thickness from 6-9m, though the base is beneath the road level. The exposed thickness of the upthrown original sandstone sheet is 3-6m. Within the downthrown block, the 45m long northwestern part is undeformed (Plate 108), but the 30m long southeastern part is deformed to various degrees (Plates 109-110, Figs. 74 & 75).

The plane of the minor fault XX' is conspicuously marked out at a point 50m southeastwards from the northwest end of the downthrown block by a surface demarcating the abrupt termination of strata (Fig. 74, Plate 109). This fault plane of XX' has a curved cross-sectional profile, which is steep at the top (70^{o}) but flattens gradually downwards and also dips to the northwest. Its throw measured at the top parts is 1.5m, and the width of its plane is 1-3cm. The minor fault ZZ' is restricted to the southeastern part of the quarry as shown in Figure 74. The 9 small faults (F of Fig. 75) are generally steep.

Also associated with these faults within the downthrown block starting from the road level to a 6m height is fold deformation. The degree of deformation at the 10m long northwestern part is less than at the 20m long southeastern part where there is also a general sandstone bed deficiency.

The deformational structures involve several types of fold as well as balls and pillows,and faults (Fig.75). Within the distinguishable stratification, all degrees of cohesion occur ranging from parallel stratified laminae through undulating laminae often twisted or wrinkled in a horizontal plane to laminae encircling the different balls concentrically. All orientations of the balls ranging from horizontal through inclined to vertical are present. The folds are dominantly inclined or upright in attitude, often open and generally rounded in shape.

Orientation of the folds

Efforts were made to measure the fold parameters as was done in section 3.6.3.2. The directional data measured are presented in Figure 76. Fold plunge was generally low, commonly less than 5^{0} and so was ignored. The fold axis orientation is unimodal, trending dominantly about 315^{0}-135^{0}. There is a wide scatter of the dip direction of axial planes, however, it appears that a dip to the southwest is dominant, suggesting that any slump movement was probably towards the northeast (cf. Woodcock 1976).

Genesis of the Structure

Faulting and folding are thought to be related and probably syn-sedimentary as will be discussed below.

The interpretation of the genesis of the faults is problematic because of the unknown thickness factor discussed below which is relevant to the interpretation. Based on the exposed observable structural and lithological thickness relationship it may be tempting to invoke the involvement of growth faulting. However, several problems particularly the thickness factor beset such an interpretation. The exact thickness differences between the upthrown and the downthrown blocks of the prominent fault YY' is difficult to establish with any confidence due to the fact that at the upthrown block, the top of the exposure may not necessarily correspond to the top of the sandstone unit. Therefore even though the base of the sandstone unit is well exposed, the apparent thickness of the upthrown block at the exposure may not be its true thickness; after all it is not clear what thickness of this upper sandstone unit is eroded. Also, while the top of the downthrown block is conspicuous, its base is not exposed. Added to this thickness factor is the directional factor. The direction of movement of the downthrow block and also the slumps is in conflict with that of the palaeocurrents as shown by Figure 76.

In view of these problems, the following model appears more appropriate to account for the origin of the faults and the associated slump structure (folds).

Channel Bank-failure Model

Over-steepening of channel banks often result, due to scouring during high river stage consequently inducing failure of the wetted sediments along rotational slump planes during the subsequent lower river stage. The entire bank is frequently slumped. According to Stanley _et_ _al_. (1966) and Laury (1971) if the basal shear plane extends beneath the base of the channel, the slumped sediments may be preserved below the channel facies. In this model, YY' represents the shear plane, XX', which may be syn-sedimentary affected the downthrown block only and ZZ' is responsible for the remarkably thick sandstone body exposed at the southeastern part of the exposure (Fig. 74). The mudstone occupying the FF' fault-zone may have intruded this zone, or probably arose from the original mudstone interbed and have consituted a mere smear on the fault plane.

Large scale channel bank slumping such as is suggested here is widely accepted (McCabe 1975, Elliott 1978) as an important feature of distributary channels.

4.3.1.2. SHEET CHANNEL SUB-ASSOCIATION

Introduction

The channels described under this sub-association have been defined above in the Introductory part of the Distributary Channel Association. Sheet channels are volumetrically important occurring in all three chrono-stratigraphical intervals of this study (Table 19).

Description

The erosion surfaces at the bases of sheet sandstones are broadly horizontal and laterally extensive, often traceable in outcrop over hundreds of meters, usually ranging from some 100m to 500m. The latter extent was derived from Braithwaite Quarry (SE 040418) another operating quarry where excellent cliff-face exposure portrays the presence of 2 channels in the quarry. The horizontal erosional surface underlying the upper channel can be easily and continuously traced all along the 500m long and some 300m wide extents of this quarry. Exposures at Readyshore Scout (SD 942198) and Scout End (SD 942189, 15-20m level, h, Fig. 16) also provide continuous lengths of 350m and 300m respectively of these channels. Erosion surfaces are commonly overlain directly by dumped drifted plant fragments (Plate 105), or logs of wood (Plate 106) or abundant mud clasts (Plates 107, 105), and sometimes these mudclasts are aligned with their long dimension parallel and along the cross-bedding planes (Plate 47). Erosion surfaces can be rich in flute marks as best occurs in Readyshore Scout. Channel margins were not seen, and so estimation of channel widths is not possible.

Channels of this sub-association can be filled both by medium-grained sandstone and by coarse-grained to very coarse grained sandstone. No fining upward tendency was observed. Their sorting compares with those of the major channels described earlier. The lithofacies occurring within these channels include the following: 17, Massive Sandstone; 11, Tabular Cross Bedded Sandstone; 10, Trough Cross Bedded Sandstone and 20, Seatearths and Coals. The vertical order of these lithofacies are shown in Table 19. As is clear from this table, erosion surfaces overlain by either lithofacies 11, Tabular Cross Bedded Sandstone or 10, Trough Cross Bedded Sandstone are common. Except in a few cases shown in Table 19, only one sedimentary structural type makes up the entire sheet sand bodies. For instance, in Readyshore Scout, each of Channels 1 and 2 are filled by a coset of Lithofacies 11, Tabular Cross Bedded Sandstone, while Channel 3 (the top channel) is filled by only a coset of Lithofacies 10, Trough Cross

Bedded Sandstone. Channels 2 and 3 of Readyshore Scout are well shown in Plate 107 (see hammer at base of Channel 2). In general, the sheet channels of this study area are sandstone dominated.

Most channel fill thicknesses lie between 1 and 10m (commonly 2-4m). In many cases, however, the basal erosion is not seen. Also in a multi-storey unit it is common for the upper part of a unit to be removed by a post-depositional Recent erosive phase. This tendency for the basal erosion surface not to be exposed and for the uppermost channel unit to form the topographical feature results in many cases, that only minimum thicknesses are obtainable. Where the top of the uppermost channel of a multistorey unit is exposed, its thickness is regarded as most reliable since its top was not truncated and its erosion surface is observable.

Interpretation

The interpretation of the sheet channels of this study is problematic, because, steep sided, flat bottomed sand bodies are often associated with Allen's (1963) Epsilon Cross-bedding and therefore attributed to meandering streams. In such a setting, a laterally migrating channel cuts a horizontal erosion surface, similar to those of this sub-association, and by removal of one bank and lateral accretion of the other, lays down a tabular sandstone unit. The problem here is compounded by the fact that channel margins are not seen. Also Epsilon cross bedding was not identified. Although Moody-Stuart (1966) implies that absence of Epsilon Cross Bedding indicates low sinuosity, Collinson (1978b) contends that such absence does not rule out the involvement of point bars.

The sheet sandstone units of this study is however thought to be of low-sinuosity origin, particularly due to their sand-choked character (using Campbell's terminology) but also because of the general absence of fining upwards tendency.

4.3.2. INTERDISTRIBUTARY COMPLEX ASSOCIATIONS

4.3.2.0. Introduction

The interdistributary bays referred to here include all bays between deltaic distributaries, irrespective of whether such bays are open to the basin, or partially or entirely closed (Coleman et al. 1964). This association which is volumetrically significant due to its widespread nature is generally haphazard in organization. Excepting Lithofacies 3, Bluestone, all the fine-grained lithofacies described in Chapter 3 occur in it. In addition, Lithofacies 10, Trough Cross Bedded Sandstone; 15, Lenticular Bedded Sandstone, and 16, Parallel bedded Sandstone constitute the coarse-member constituents of this association. Lithofacies 20, Coal on Seatearth is widespread and is generally confined to the top parts of which-ever sequence it forms a part. The bedding of the coarse-member constituents which are frequently thin (commonly 5-30cm thick) are generally horizontally lying. Most boundaries are gradational, though sharp ones occur, and burrowing is often intense (Fig. 77, 6.8 - 7.4m level). It would appear that the intensity of burrowing is partly controlled by the lithology. Discussion of this view will be made in Chapter 5 dealing with trace fossils. Even though the vertical order of these lithofacies may appear chaotic the following genetic groupings of lithofacies are distinguishable

(i) Alternating Tabular Bedded Sandstone and Mudstone Units.

(ii) Alternating Lenticular Sandstone Beds and Mudstone Units.

(iii) Channel Unit cutting into sharp based Tabular Sandstone.

(iv) Gradationally based Sandstone Units.

4.3.2.1. Alternating Tabular Bedded Sandstone and Mudstone Units

This involves an alternating sequence of intensely bioturbated, tabular, commonly 10-60cm thick Lithofacies 8, Trough Cross Laminated Sandstone and Lithofacies 5, Mudstone and Siltstones, usually rich in plant fragments. All the gradations of Lithofacies 5 discussed in section 3.5.1. particularly mudstone with rippled lenses of siltstone or fine-grained sandstone occur in between the sandstone units. Sandstone bed boundaries are commonly sharp, though gradational sandstone beds occur locally. This type of lithofacies grouping commonly generates coarsening upward sequences, often marked by an upward increase in sandstone thickness. A typical instance of this grouping is seen at Harper Clough (SD 717316) at 2.5-4.2m, 4.2-5.9m, 8.5-16.4m and 16.9-19m levels (Fig. 78B), with each of the levels portraying a coarsening upwards sequence. The sequence at 8.5-16.4m level is striking, not only because it ends in Lithofacies 10, Trough Cross Bedded Sandstone, but also because of the fine preservation of the sinuous dune crest at its top (Plate 38). The tree trunk in growth position (Plate 40) also preserved on top of Lithofacies 10, is another spectacular feature of this sequence in this quarry. Twelve roots which show surface scar pits (Plate 41) radiate in an excellent preservation state. Lithofacies 10, is also intensely bioturbated (Plate 111). Whenever sharp bases characterise the tabular sandstones of these units they are usually prominent in the sequence. Such distinctive sharp bases involving even Lithofacies 16, Parallel Sided Sandstone occur at Foster Clough (SE 020276, Fig. 77, 15.2-15.4m, Plate 7B) and Woodhouse Quarry (SE 062397, Fig. 82, Plates 7A). Current rippling (Plate 7A) or rare wave rippling (Plate 24) makes the upper parts of some of these sandstones irregular. Flutes, groove marks and load structures occur at the bases of some of these Parallel Sided Sandstones of Woodhouse Quarry and Foster Clough Quarry.

4.3.2.2. Alternating Lenticular Sandstone Beds and Mudstone Units.

The same lithofacies relationships described in section 4.3.2.1. occur here except that several of the sandstone units involved occur as lenses of various dimensions. Lithofacies 16, Parallel bedded sandstone occurs also in this sequence. In most cases the irregular tops due to wave or current ripples occur. The best development of this grouping occurs at levels 26-28m (Plate 82A), 41-42m (Plate 82B), 46-50m (Plate 82C) of the northern section of Fletcher Bank Quarry (Fig. 59) and between levels 5-10m of Buckden Clough (Fig. 79). Burrowing, both vertical but particularly horizontal characterise these sandstone units.

It is noteworthy that while this sequence is sandstone dominated in the northern section of the Fletcher Bank Quarry (Plate 82A) its lateral equivalents in the cental and southern parts are dominated by Lithofacies 5, Mudstonesand Siltstones. For instance, whereas the three distinct lithofacies in the northern section of Fletcher Bank include 5, Mudstone and Siltstone; 15, Lenticular sandstone beds; 16, Parallel bedded sandstone the following lithofacies occur in the Central and Southern vertical sections (listed in a decreasing order of abundance); 5, Mudstones and Siltstones; 6, Siltstones; 1, Unfossiliferous Mudstone, usually in a homogenous character; 7, Rippled silty sandstone, usually fine to very fine-grained; 8, Trough Cross Laminated Sandstone (Plates 17, 22, 25-26). The lengths of some of the lenses in the northern section is some 100m and thickness some 30cm (Plate 82A).

In the Central parts of the Fletcher Bank Quarry (Fig. 59) convolute bedding occurs at 36.7-37m level, involving Lithofacies 6, Siltstone. However, even though the siltstone laminae are thrown into convolutions, the folds can still be traced laterally for up to 50m.

4.3.2.3. Channel Units Cutting into sharp based Sandstone/Mudstone Units

The sequence here is similar to either section 4.3.2.1. or 4.3.2.2. above except that a commonly sharp and relatively thick sandstone unit scours into the upper parts of the sequence as is well shown in 25.3m level of Warland Wood Quarry (SD 948203, Fig. 24), and 9.8 level of Scout End (SD 942180, Fig. 80). Some of these channels may be rich in rootlets, which may be confined to their tops such as at Warland Wood (levels 28.8-30m, Fig. 24) or scattered all through the body such as at Cowloughton Clough (Plate 98, Fig. 78A) and Wardhouse Quarry. Excellent _in situ_ stigmaria roots may be abundant in the channel unit (Plates 94, 95 & 112). Bioturbation may destroy stratification within the channel units (Plate 29) and sometimes display excellent sand-filled conical depressions (Plate 98). At Warland Wood Quarry, surfaces reflecting discharge fluctuations (26.2m, 27m, 27.8-29m, Fig. 24) appear to have provided favourable localities for the activities of the burrowing organism because numerous "bioturbation ridges" (details of these are given in Chapter 5), are preserved at the bases of the mudstone unit immediately overlying such surfaces. Flutes may be locally abundant at channel bases such as Cowloughton Clough and have provided reliable channel flow direction indicators.

4.3.2.4. Gradationally based Sandstone units and channels

The sequence here commonly starts with a bioturbated Lithofacies 2, Unfossiliferous mudstone or Lithofacies 5, Mudstone and Siltstone and gradationally alternates upwards with tabular bedded siltstone or sandstone units. Sandstone units here are either Lithofacies 8, Trough Cross Laminated Sandstone or 9, Parallel Laminated Sandstone. The tops of the sandstone units are commonly irregular due to rippling which may be symmetrical as at Foster Clough 7.3m level (Fig. 77) or asymmetrical. This sequence differs from the others described above by its general lithofacies gradational boundaries as demonstrated by the sandstone beds at Holmbridge Woodhouse Quarry (SE 128065, 11.5-21m level of Fig. 81, Plates 13 & 14) and the rippling at the sandstone top which is more common here than in any of the others. The upper parts of the alternating sequence of sandstone and mudstone may or may not be eroded by a channel. Typical examples of the complete sequence of this group occur at the middle parts of the Foster Clough section 6.5-14.4m level (Fig. 77) and 25-50m level of Ponden Clough (Fig. 17). Depth intervals 93-107m of Ramsden Clough (d, Fig. 12), contains a good section of this sequence though its top contains no channel. Also 103-107m level of it is sinusoidally rippled (Plate 85).

The channel in the Foster Clough section is characterised by numerous reactivation surfaces which have become sites of concentration of Pelecypodichnus 'bumps' (hypichnial ridges, see Chapter 5) and plant remains. Lithofacies 8, Trough Cross Laminated Sandstone sandwiched in between Lithofacies 10, Trough Cross Bedded Sandstone at 27.8-29m level in Warland Wood (Fig. 24) are other indications of discharge fluctuations. In some localities these channels lie directly on seatearth horizons or on coal (53m level,"f" of Fig. 16).

Interpretation

Context

The prevalence of of seatearths and coals, the occurrence of wave ripples and the dominance of mudstone units which frequently contain cross stratified current ripples indicate an environment shallower than the Slope Association. Also the trend towards upward increase in burrowing, the general smaller thicknesses of the sequences described above appear to support this suggestion. Above all the general setting of the sequences commonly above and between the distributary channels appear to verify their interpretation as deposits of shallow bodies of standing water between distributary channels, otherwise termed Interdistributary bay sediments. Although the definition of Interdistributary bay of this study is meant to be an all inclusive one, that is, without discriminating whether the bays are open to the basin or closed, the general lack of evidence of tidal processes and beach and barrier deposits suggest that the Interdistributary areas of this study may after all be open to the basin, but with fluviatile processes dominant.

Sequences

The upward coarsening alternating sandstone and mudstone units of 4.3.2.1. are regarded as levee progradation units. Such alternating sediments are often the result of suspended sediment fall-out in the interdistributary areas especially since their abundant rippled lenticles often indicate shallow conditions. The tabular geometry of their coarse fraction probably reflecting the fact that they may be sheet flow sediments which spilled over channel banks. In such a setting, the fine-grained sediment is spread over the entire bank, while the coarser sediment is restricted to the confines of the bay margins and so contributes to levee build-up. Since levees fine away from the channel margin, a coarsening upward sequence characterised by interbedding with increasing thickness of the coarse beds upwards results when the levees encroach into the bays, as is demonstrated by the units at Harper Clough, and Coster Clough already mentioned in 4.3.2.1. Good examples of similar coarsening upwards occur also at 86.8 - 90m level of Ramsden Clough and 0-5.8m level of Buckden Clough (Fig. 79). Coal on seatearth, which are signs of emergence that are diagnostic of levees (Fisk, 1947, Allen 1965) characterise the Harper Clough sequences. It is also generally accepted that levees provide suitable conditions for the growth of trees in a deltaic setting (Leblanc, 1965, in Scott & Fisher 1969, Fig. 22), and the presence of the tree trunk in a growth position at Harper Clough sequence is a positive arguement for the levee interpretation. Other supporting evidence for the levee interpretation seen at Harper and other sequences with the same interpretation include, bioturbation, abundance of plant remains, types of sedimentary structure and lithology. Assuming that the levee interpretation is appropriate, the presence of parallel sided sandstone in such a setting implies that the lithofacies is capable of developing in a shallow water environment. In this context, the sandstone units are considered as a product of episodic decelerating flow following Collinson (1978a), and the sole marks at the base probably reflects the suddeness of the detrital incursion. The presence of current rippled or wave rippled tops is evidence of reworking activities of these agents. The levee successions described here resemble sequence "B" of Elliott (1974).

The lenticular sandstone beds and mudstone of 4.3.2.2. are regarded as the crevasse splay sediments in which the lenticular sand bodies represent the "numerous small, anastomosing streams" of Elliott (1978). The predominance of coarser sediments over the finer ones noted in the northern part of Fletcher Bank as against the situation occurring at the Central or South parts of the quarry, may be due to the proximity of the northern areas to the active distributary channel providing the sediments or due to the sediments available to the currents that deposited them. Abundance of rippled lenticles occurring in between the sandstone bodies are fair indication of shallow depth. The presence of parallel sided sandstone in this environment is interpreted in a similar way as was done in the case of section 4.3.2.2.

Various theories have been put forward to explain the genesis of convolute bedding, however, differential liquefaction appears the most acceptable cause (Williams, 1960; Wunderlich 1967).

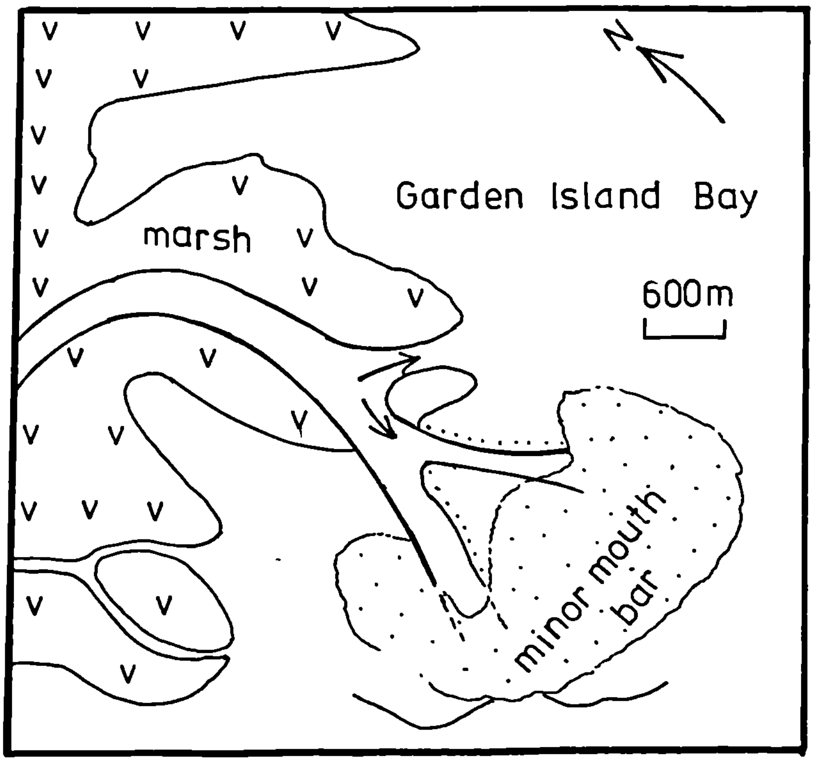
The channel units described in sections 4.3.2.3. and 4.3.2.4. are regarded as crevasse channels, particularly because of their settings, but also based on their thickness, general scour bases which are commonly marked by various lag concentrates. Their numerous indications of discharge fluctuations particularly their several multiple erosion surfaces well shown at Warland Wood and Foster Clough Quarries are diagnostic of crevasse channels. This is because crevasse channels are commonly subject to fluctuation in discharge due to the fact that they are often abandoned after floods. However, channels of considerable depth may remain open (Elliott, 1974). The abundance of rootlets within these channel units, particularly those associated with _in situ_ stigmaria (Plates 94 & 95, 112), or on top of the units 12.3-13m level Scout End (Fig. 16) are further evidence of temporary channel floor emergence.

The flutes at the base of some of the channels are probably reflecting the suddeness of the incursions of these relatively coarse sediments into an environment otherwise accumulating fine sediment.

The gradationally based tabular sandstone units discussed in section 4.3.2.4. are thought to represent minor mouth bar sediments which are commonly characterised by a gradationally coarsening upward sequence (cf. sequence F, Fig. 1, Elliott 1974). Such a sequence is seen at Foster Clough section mentioned in section 4.3.2.4. and is thought to record the passage from a fine-grained interdistributary bay facies

Fig. 83.

Model of Minor Bar Crevasse Channel Couplet.



upwards into progressively coarser detritus introduced by crevasse channels. A modern analogue of this sedimentation style originally proposed by Coleman *et al.* (1964) and elaborated by Elliott (1974, 1978) is shown in Figure 83). The symmetrical rippled tops at Foster Clough and the asymmetrical rippled tops at Ramsden Clough, 88m level (d, Fig. 12) reflect limited wave and current reworkings respectively and are common phenomenon at this type of setting (Coleman *et al.*, 1964). Admittedly, the mouth bar sequences at Ramsden Clough 13m thick (93-106m level, d, Fig. 12) and Ponden Clough 11m thick (26-41m level, f, Fig. 17) are unusually thick but there seems no reason why such thick sediments cannot be preserved at such a setting as long as a very active deposition is accompanied by a high subsidence rate. Furthermore, all gradations of scale of mouth bar, "major" or "minor" are not well separated classes. The minor mouth bar sediments at Foster Clough (Fig. 77) and Ponden Clough (f, Fig. 17) are truncated by crevasse channels in an analogous manner to the model in Figure 83.

4.3.3. ABANDONMENT LITHOFACIES ASSOCIATION

4.3.3.0. Introduction

Abandonment lithofacies are generated on a moribund delta lobe due to a shift in the point of a sediment supply from the erstwhile delta. Such a shift results in the abandonment of an active delta and the initiation of a second cycle related to a new point source. The abandoned delta, having been deprived of nourishment, undergoes coastal retreat and inundation due to continuing subsidence. During this time, reworked and *in situ* deposits accumulate over the detrital lens, forming what has variously been termed bounding sediments (Coleman & Gagliano, 1964), destructive facies (Scott and Fisher, 1969) and abandonment facies

(Elliott, 1974b). The term abandonment lithofacies will be used in this work, following Elliott's (1974b) contention that the term 'destructive phase' is misleading somehow since only the shoreline area of the lobe is reworked while the remainder, which is often draped, is preserved and not destroyed.

4.3.3.1. Description

Lithofacies 20, Coal on seatearths; 1, Unfossiliferous Mudstone and 2, Fossiliferous Mudstone are included in this association. The order of occurrence is for lithofacies 20 to terminate a preceeding sequence whose top is commonly a sandstone member. Lithofacies 2, which commences the succeeding sequence is separated from Lithofacies 20, Coal on seatearth by Lithofacies 1, Unfossiliferous Mudstone whose common thickness range varies from 0 to 3m. Tables 3 to 8 give full details of these thicknesses at the various localities. Lithofacies 20, which commonly involves coal on seatearth may be represented locally by either or both member, though more often by seatearth. The lithofacies is relatively thin (already discussed in section 3.20.1.) though by comparison is generally thicker than those reported by Collinson (1967), McCabe (1975) in R_1 succession of this basin and by Baines (1977) in the E_{1c} succession also in the Central Pennine Basin. The thickness ranges of the intervening Lithofacies 1, Unfossiliferous Mudstone and those of Lithofacies 2, have already been discussed in sections 2.2. and 3.2.1. respectively.

4.3.3.2. Occurrence

Lithofacies 20, Coal on Seatearth are most commonly found on top of distributary channels as is shown at the following localities listed according to their area (depths quoted below are approximate).

(i) Area 3: Wicking Crag 41-43m level (b of Fig. 15).

(ii) Area 4. Hodge Clough 10-12m level (c of Fig. 16).

(iii) Area 4. Fletcher Bank Channels 3, 4, 5 (e of Fig. 16).

(iv) Area 4: Tower Hill Side 51-52m level (f of Fig. 16).

(v) Area 4: Gorpley Clough 99-101m level (g of Fig. 16).

They are also common on the following deposits of the Interdistributary Complex Association (depths quoted below are approximate).

(i) Crevasse Channels: 12.2-13m level,h & 13-13.3m level, i (Fig.80).

(ii) Crevasse Channels: 60.8-61m level (Fig. 78A).

(iii) Levee 5.8-7.2m, 7.2-7.5m, 7.5-8.5m, 8.5-9m, 16.2-16.8m (Fig. 78B).

It is noteworthy that Lithofacies 20, Coal on Seatearth is also noted on mouth bar sediments such as the following shown below (depths quoted below are approximate).

(i) 49-50m level a (Fig. 14).

(ii) 26-26.9m level d (Fig. 15).

(iii) 17-18m level b (Fig. 16).

(iv) 63-64m level c (Fig. 16).

(v) 18-19m level f (Fig. 17).

4.3.3.3. Distribution

Even though this, Lithofacies 20, Coal on Seatearth appears widespread as is indicated by its distribution below R. bilingue typical band in areas

2, 3 (Figs. 14 to 15) and below R. bilingue late band in areas 2 to 5 (Fig. 14-17) its absence in some of these areas is thought to be possibly due to poor exposure rather than a genuine absence.

4.3.3.4. Interpretation

The presence of a widespread coal on seatearth unit is taken to indicate an overall colonization of the delta top, including the rare mouth bar areas involved, by vegetation. Also it is an important indicator of depth (cf. Reading, 1970). In these areas involved it is thought to reflect the shallowness of standing water or moribund channel on which they deposited. Such environments must have most likely been in the interdistributary areas of fluvial-dominated delta top.

The Lithofacies 1, Unfossiliferous Mudstone occurring between Lithofacies 20, Coal on Seatearth, and the succeeding marine band is regarded as the deposit of bays which develop on abandoned deltaic lobes due to continued compactional subsidence subsequent to abandonment (Scott and Fisher, 1969).

The marine bands have been discussed in section 2.1.

The widespread nature of Lithofacies 20, Coal on Seatearth, complemented by their probable lateral continuity as postulated above may be crucial for further stratigraphic studies of the Marsdenian sediments in these areas, at least on a local basis. An indication of this spatial continuity is provided by the Fletcher Bank Quarry which provides the most continuous laterally exposed section of the Marsdenian sediments in the study area. Here, the coal layer on top of its Channel 3 is laterally continuous for over 800m, the maximum lateral extent of this quarry.

The thinness of the coal layers may be suggestive of the high input of detrital sediments in this basin. Usually where sediment input is moderately low and the basinal energy is relatively high, the abandonment lithofacies largely makes up the greater part of the preserved delta deposit (Scott & Fisher, 1969), Also the fact that the constructive and abandonment lithofacies are vertically distinct is an evidence that this delta is probably river dominated (Scott and Fisher, 1969). The implication in such a vertical distinction is that marine processes did not rework the detrital sediments substantially after delta abandonment. In other words, this is evidence in support of a river-dominated delta since, in tide- or wave-dominated deltas, constructive and abandonment lithofacies are often not as vertically distinct due to appreciable reworking after abandonment (Scott & Fisher, 1969). These authors also contend that the relative importance of abandonment lithofacies increases in a spectrum from high constructive elongate to high constructive lobate and finally into their "high-destructive" delta systems.

4.3.4. Relationships within the Delta Top Assemblage

Description

The Distributary Channel Association commonly occurs at the base of the assemblage. Frequently, they have been seen to even cut down into the Slope Association as shown by the following.

(i) Bare Clough, 15-20m level (a, Fig. 14), Scotland Flags.

(ii) Red Lane Dike, 42-46m level (d, Fig. 14), Scotland Flags.

(iii) Wicking Crag, 18-23m level (b, Fig. 15), Pule Hill Grit.

(iv) Fletcher Bank, 252-276m level (e, Fig. 16), Pule Hill Grit.

(v) Rake Dike, 75-83m level (c, Fig. 14), Pule Hill Grit.

(vi) Harper Clough Quarry, 44-60m level (b, Fig. 17) Hazel Greave Grit.

In these cases it becomes usually problematic to draw a definitive boundary between the Delta Top and the Underlying Delta Slope.

Within the major channel sub-association, there is commonly one set of Lithofacies 12, Large Scale Cross Beds, wherever they occur. Occasionally, however, 2 or very rarely 3 sets may occur. Cosets of medium scale cross beds usually occur above large scale cross beds wherever both lithofacies occur together such as at Fletcher Bank section. Interdistributary Complex Association are more frequently seen on top of the Distributary Channel Association, although they can also occur below them in some localities more often in the Pule Hill and Hazel Greave Intervals (Figs.15, 16 & 17). Abandonment lithofacies association whose dominant members are coal and seatearths are often associated with interdistributary complex associations, distributary channel associations and rarely the upper parts of the delta slope association.

This assemblage, as a whole, is interpreted as a delta top sequence. Its areas of shallow water are represented by the interdistributary complex association and the lithofacies described with it are consistent with those described by Coleman and Gagliano (1965) and Oomkens (1974) for such environments in the Mississippi and the River Niger respectively.

The restriction of the Channel Association to the bottom of the assemblage suggests that they are distributaries similar to those of Fisher (1969) which are straight in their reaches, with transverse bars (Leopold and Wolman, 1957). The absence of thick channels high in the sequence, the thinner nature of the sequences in the Interdistributary Complex Association and the general lack of large bedforms in the Association indicates that channels upstream of the major distributaries were shallower.

In conclusion the presence of a widespread coal on seatearth indicates an overall colonization of the delta top by vegetation. Also the several seatearths and coals seen in some sequences may be reflecting influence of subsidence and transgression, forming interdistributary areas.

4.4. SUMMARY TO FACIES ASSOCIATION

Based on the overall vertical relationships starting from the Deep Water Association through the Delta Slope Association to the Delta Top Assemblage, the sedimentological succession is considered as an essentially regressive deltaic sequence.

CHAPTER 5: TRACE FOSSILS OF THE MARSDENIAN SEDIMENTS

5.0. INTRODUCTION AND DEFINITION

The format adopted below for the description of the trace fossil is an integration of the modified versionsused by Fursich (1974) and Hantzschel (1975). First, the illustrations utilized for each trace fossil are cited. The morphological description and the preservation of the trace fossil follow. Under the next subheading entitled, "Location and Age, Facies and Sedimentological Context", the location of the trace fossil being considered, is mentioned under "Association". The final sub-heading entitled "Discussion", deals with the interpretation of the probable producer of the trace fossil. Where necessary, expanded remarks of the sedimentological context of the trace fossil are made under "Discussion".

The terminology employed in describing the preservation of the trace fossil follows the work of Seilacher (1964a; Fig. 92) and Martinsson (1965 & 1970, Fig. 93). These workers based their trace fossil classification mainly upon stratonomy (otherwise called toponomy) which simply means the position of preservation of the trace. As shown in Figure 94, there are 2 principal varieties of preservation, namely full relief and semi-relief. In full relief the entire structure is preserved and this often arises when the animal burrows at some depth below the surface through a homogenous sediment. The burrow could be packed with fecal material. In semi-relief, only the top half or the bottom half of the burrow structure is preserved. These are usually the most common trace expression. Preservation is often easier on a bedding surface where the adjacent stratum is of different lithology (Osgood, 1970). When preserved on the upper surface of a stratum, trace fossils are termed epirelief, but when on the bottom surface hyporelief (Fig. 92). Martinsson's corresponding terminologies are shown in Figure 9 3. These are purely descriptive terms.

Even though concave imprints constitute the most common expression of epireliefs and hyporeliefs convex fillings, either may occur. Seilacher's (1953) "ethological classification", that is, classification based on the behavioural response and purpose of the trace making organism will be employed also.

Seilacher's (1953) classification, together with the relevant features of each group is given below.

(i) Paschichnia (Grazing Trail): the winding and meandering trails and burrows of vagile mud-eating organisms.

(ii) Fodinichnia (Feeding Structure): Extensive burrow and tunnel systems made by hemisessile sediment eaters.

(iii) Domichnia (Dwelling structures): Permanent domicile burrows made by vagile and hemisessile organisms, feeding without the sediment, e.g. predators and filter and suspension feeders.

(iv) Repichnia (Crawling traces): Trails, burrows and tunnels left by vagile benthos during locomotion.

(v) Cubichnia (Resting traces): Resting marks (or body impressions) left by vagile organisms temporarily resting on the sea floor.

The main advantage of this ethological classification is that it solves the problem created by the common difficulty in identifying the producer of most traces. It also reflects the thinking of Seilacher and other trace fossil workers like Hantzschel and Richter who opposed the traditional zoological oriented view that a student of trace fossil is dealing with remains of an organism as shown by its activity. This placed emphasis on naming the organism as reflected by the trace rather than the trace itself. Seilacher and his group contend that trace fossil should be studied as an independent activity and not as "a proxy for the originator", and so the main value of the trace fossil should be ecological rather than morphological (Osgood, 1970),

Following Häntzschel (1975) and Hakes (1976), the trace fossil names mentioned in this work are classified as ichnonogenera and ichno-species, because they quickly remind the reader that he is dealing with trace fossils. For the purpose of description, the trace fossils treated below are grouped into 2 categories namely those with formal names which are discussed first,and two,other trace fossils with informal names which are treated second. All the trace fossils to be discussed are listed below:

CLASS A. Those with Formal Names.

1. Arenicolites
2. Arthrophycus
3. Cochlichnus
4. Gyrophyllites
5. Kouphichnium
6. Palaeophycus
7. Pelecypodichnus
8. Phycodes curvipalmatum
9. ?Phycodes palmatum
10. Planolites
11. Olivellites
12. 'Scolicia'
13. Zoophycos

CLASS B. Those with informal names.

1. Loop and sinuous trails.

The ichnogenera are discussed below in alphabetical order as listed above.

5.1. Ichnogenus Arenicolites carbonarius Binney 1852 (Hardy 1970 Revision).

Plates 114, 115, 116, 117. Figure 94. Table 20.

5.1.1. Description and Preservation

The burrows are dominantly preserved as vertical U-shaped endichnial tubes within 3-5cm thick interbeds of fine-grained, well-sorted sandstone (Plate 114). In a few cases negative epirelief consisting of small elongate depressions (commonly 8mm long, 5mm wide and 3mm deep) exposed in plan view represent this burrow. In some of these cases the depressions are in direct contact with their underlying U-shaped tube. The vertical U-tubes are easy to identify because of their colour contrast with the host rock. The tubes are generally lined by dark grey micaceous mudstone which contrasts with the brownish grey colour of the host sandstone. However, the colour of the sandy infilling which is retained in many samples is undistinguishable from that of the host rock, but even in these cases the background lining makes the fill recognizable. Also incomplete filling only leaves the dark grey trace which portrays the course followed by the producer. The U-tubes are generally limited to the upper two-thirds of their sandstone host beds (Fig. 94). Both limbs of the structure open into a funnel (Plate 115) except where erosion has cut off the upper part, in which case the burrow may appear to terminate without a funnel. Plate 116 portrays the irregular sandstone top surface which corresponds with the levels of the truncated tops of the U-tubes. The burrows can be either simple or composite. Out of the 16 specimens studied in detail, 10 were simple having 2 limbs. The remaining 6 composites can possess 3-4 limbs as shown in Figure 94 and Table 20. In some of the composite

Sample No.	Form				Funnels		U.Tube Diam Mms.	U Tube Width Mms.	U Tube Depth Mms.	Host Bed Thickn.
	Simple		Composite		No.	Diam Mms.				
		No. of limbs of U exposed		No. of limbs of U exposed						
1	X	2			1	12	7	40	20	34
2	X	2(each)			2	10,12	4,4	38?,25	15,22	34
3			X	3	1	14	5,4	63	23	34
4	X	2			1	12	6	?	30	34
5			X	4	T	-	5,1,1	37	20	32
6	X	>(each)			>2	17,11	4,6	?	25	33
7	X	2			T	-	5	40	20	35
8			X	3?	T	-	4,9	>42	24	40
9	X	2			2	9,7	4	55	26	40
10	X	2			T	-	5	52	20	40
11	X	2			T	-	4	27	20	40
12			X	4	3	10,10,14	5	55	22	32
13			X	3	3	3,3,2	1,1,1	14	8	32
14	X	2			2	13,18	6	45	18	30
15	X	2			T	-	5	28	17	32
16			X	3	1	6	4	45	28	34

Table 20. The dimensions of Arenicolites Carbonarius

T = Truncated.

U-tubes, one limb appears to be much wider than the other limb (Plate 117A), and in some of such wider limbs, cylindrical sand casts whose diameter approximates one-third of the limb are preserved, usually at the outermost part of the limb (samplesXII, III, Fig.94, Plate 117B). Table 20 also shows other vital dimensions of the burrow. It is worth noting that samples II and VI (Fig. 94) are regarded as simple even though they consist of more than 2 limbs each. This is because the cross-cutting relationships between the limbs suggest that some overlapping took place. For instance, in sample II, it appears that sample IIb is overlapping sample IIa and in VI, VIb overlies VIa (Fig. 94, Plate 115). This overlapping relationship contrasts with the relationship that exist in the composite burrows where the different limbs, sometimes even with different widths joined in one common limb and lie in a single vertical plane (cf. Hardy 1970a).

5.1.2. Location and Age, Facies and Sedimentological Context.

Fletcher Bank Quarry (SD 801167); Age: Pule Hill Interval. Abundant in Lithofacies 9, Parallel Laminated Sandstone exposed in 50-51m level (Fig. 59) in the Northern Vertical Section. Here the 3-5cm thick sandstone units are interbedded with 0.2-0.5cm (occasionally 1-2cm) thick black mudstone. Although the burrow is most abundant in the level pointed at by the pencil in Plate 114, it occurs also in some overlying and underlying sandstone units. The sandstone beds are thought to be of Crevasse Splay origin.

5.1.3. Association

Pelecypodichnus which occurs as epichnial grooves or hypichnial ridges on the top and base respectively of some of the sandstone beds containing the U-tubes. The epichnial groove can be slightly elongate or circular. Diameter of such circular pits is 3mm. Length of elongated grooves range from 1-1.5cm, width 3-5mm and depth 2mm. Length of the elliptical bulges ranges from 6 to 10mm, width 3 to 5mm and relief 5 to 8mm.

5.1.4. Discussion

Dwelling burrow (Domichnia) of suspension feeders which colonized sand surface during periods of retarded mud supply. Overlapping of limbs suggests slight vertical movement of U-tube (Pollard, pers. comm., 1981; cf. A. variabilis, Fursich, 1974). The composite burrows are regarded as responses of the producer organism to accommodate growth, following Hardy (1970a). The wider limbs of some tubes probably represent the sideway excavation of the tube duringlater growth stages, when the organism prefers this side movement to constructing an entirely new tube. Hardy (1970a) contends that only the last part of such wide tubes are preservable by a solid sand cast, after the animal died. A similar observation made in this study appears to verify Hardy's contention. The suspension feeders envisaged here are probably annelids, which might be similar to the modern lug-worm Arenicola marina. However, the sedimentological context of this trace fossil suggests that the worm lived in a non-marine shallow water environment. This interpretation is consistent with Hardy's (1970a)who suggested a non-marine environment for the Bradshaw Arenicolites, which he studied. This was based on the association of the trace fossil with other non-marine burrows.

5.2. Ichnogenus Arthrophycus Hall 1852

Plate 82A, 118. Figures 59 & 95.

5.2.1. Description and Preservation

Horizontal, tube-like trace preserved as convex hyporelief at the base of a lens-shaped medium-grained sandstone underlain by mudstone. The tube appears parallel- to sub parallel-sided, except towards its ends where it tapers. Subquadrate in section. The tube diameter ranges from 3 to 12mm, though commonly 7mm. Relief is commonly 8 to 10mm. The tubes are dominantly branched (Plate 118, Fig. 95). The branching angle of up to 80^0 is common. Mutual cross-cutting of the tubes occurs. Tubes are commonly bilobed. The median longitudinal furrow, together with regularly spaced transverse annulations of the tube are conspicuous in some tubes but are faint or absent in others (Figure 95). The spacing of annulation ranges commonly from 1 to 2mm.

5.2.2. Location and Age, Facies and Sedimentological Context.

Fletcher Bank Quarry (SD 806167); Age: Pule Hill Interval. Abundant in Lithofacies 15, Lenticular Sandstone Beds exposed in the northern parts of the Quarry (26-28m level, Fig. 59; Plate 82A). The sandstone is quartzitic and well sorted. The lens is underlain and overlain respectively by 12cm and 51cm thick dark grey mudstone with light grey thin parallel interlaminae of siltstone. Lens is regarded as Crevasse Splay sands within an Interdistributary Bay (cf. Elliott, 1974).

5.2.3. Association

Palaeophycus; Planolites; Pelecypodichnus

5.2.4. Discussion

Interfacial feeding burrow system of worm or probably arthropod (Häntzschel 1975, pW38).

5.3. Ichnogenus Cochlichnus. Hitchcock 1858

Plate 119. Figure 96.

5.3.1. Description and Preservation

A meandering trail preserved as a hyporelief ridge on a micaceous medium-grained well sorted sandstone. The common prominent length of the trail ranges from 5 to 8cm, width commonly 0.5cm, relief 0.3-0.5cm, with a common wavelength of some 3cm and amplitude that ranges from 1 to 1.5cm (Plate 119).

5.3.3. Association

Pelecypodichnus, ?Phycodes palmatum, Planolites, Kouphichnium rossendalensis, Gyrophyllites. All these occur in one bedding plane (Plate 119).

5.3.4. Discussion

Crawling traces (Repichnia) of a probable worm-like organism.

5.4. Ichnogenus Gyrophyllites Glocker 1841

Plates 10A & B, 119 & 120. Figs.15 & 96.

5.4.1. Description and Preservation

A rosetted structure preserved as a hyporelief mound in a micaceous medium-grained well sorted sandstone. Can be circular but generally ellipsoidal in plan view. The diameter of the longer axis ranges from 20 to 60mm, and the shorter axis from 19 to 39mm. The trace fossil consists of a central structure from which lobes protrude radially outwards (Plate 119, Fig. 96). The central structure is polygonal and has a diameter range of about 4 to 14mm. The central structure appears broken off in some examples, probably accidentally. The radiating lobes, which are dominantly poorly lobate, enlarge distally. 5-7 lobes commonly occur in each structure (Plates 119 & 120).

5.4.2. Location and Age, Facies and Sedimentological context.

Parkwood Quarry 3 (SE 067406); Age: Pule Hill Interval. Common at the base of Lithofacies 10, Trough cross bedded sandstone of a Distributary Mouth Bar. The sandstone is well sorted, micaceous and is underlain by thin mudstone or silty mudstone. The sandstone bed is tabular and horizontal. Cross-bedding occurs both in small and medium scale sets (64-70m level, Fig. 15). Each distinct bed is a coset, commonly from 30 to 70cm thick, and is separated by easily eroded mudstone or silty mudstone unit commonly 3 to 8cm thick. Symmetrical wave ripples are conspicuous (Plates 10A & B). Tool marks and plant fragments are common.

5.4.3. Association

Kouphichnium rossendalensis, Cochlichnus, ?Phycodes palmatum, Pelecypodichnum, Planolites. All these are in bedding plane (Plate 119).

5.4.4. Discussion

Fodinichnia, in the form of radial tunnels made by unknown organism. Ichnogenus Gyrophillites has been reported only from flysch environments (Hantzschel 1975, p.W65, Ksiazkiewicz, 1970, p.283). Its occurrence in an environment that contains shallow water features particularly symmetrical wave ripples and ichnogenus Olivellites (Yochelson and Schindel, 1978) indicates that it may also be a shallow water type.

5.5. Ichnogenus Kouphichnium rossendalensis. Hardy (1970b)

Plates 119, 121A & B. Figures 97A & B.

5.5.1. Description and Preservation

Lunate shaped casts preserved as hypichnial ridges at the base of a medium-grained quartzitic, well sorted sandstone often underlain by a thin mudstone unit. The common width of the lunate casts ranges from 10-20mm (Figs. 97A & B), common relief of 3-4mm. They can occur either in a solitary form (Plate 121A) or in a group (Plate 121B). The components of a group can align themselves either along a curved trace or can cluster together randomly. Occasionally, short linear medial ridges regarded as telson casts (cf. Hardy, 1970b) occur behind some of the lunate casts (Fig. 97A). In Scout End Quarry, some of these lunate casts appear to overlie some ichnogenus Palaeophycus (top left of Fig. 97A).

5.5.2. Location and Age, Facies and Sedimentological Context

Park Wood Quarries 2 (SE 070409) and 3 (SE 067406) both of Pule Hill Interval, and Scout End Quarry (SD 944196), R_{2c}. All the 3 localities involve beds of Lithofacies 10, Trough Cross Bedded Sandstone commonly interbedded within units of mudstone and interpreted as deposited in the mouth bar areas of their deltas. Specimens of the Parkwood Quarries occur in the same level with ichnogenus Gyrophyllites whose level was mentioned in Section 5.4.2. while that of Scout End occurs in the 7m level of Figure 80.

5.5.3. Association

Pelecypodichnus, Planolites, Gyrophyllites, ?Phycodes palmatum; Cochlichnus , Palaeophycus.

5.5.4. Discussion

Burrowing (Fodinichnia) and walking trails (Paschichnia) attributed usually to anthropod which probably belongs to the genus of Xiphosurid known as Belinurus (Hardy 1970b). Telson is usually regarded as evidence of walking and Hardy (1970b) contends that Xiphosurid could have also utilized its telson as a "brake prior to touch down" after which it also served to depress its prosoma towards the sediment surface. Perhaps, the finer-grained sediment in these localities on which this Xiphosurid landed was rich in nutrients. If so the numerous lunate-cast indicate that they must have walked fairly extensively while searching and burrowing the sediments.

Kouphichnium is often regarded as a non-marine trace fossil (Hardy, 1970b), particularly because of its association with Pelecypodichnus, as occurs in this work. Both Eager (1974) and Hardy (1970b) attributed this trace to Carbonicola, a fresh water bivalve. This interpretation (that is Pelecypodichnus being derived from Carbonicola) is accepted based on the stratigraphic levels and sedimentological contexts of the litho-facies involved following Eager (1977). Pollard (Personal Comm. 1981) comments that the occurrence of Kouphichnium and Pelecypodichnus in the same bedding plane as obtains in Park Wood Quarries is unusual and probably indicates that while the arthropod was walking on the surface, the bivalve was burrowing. The occurrence of Kouphichnium on the same bedding plane with Cochlichnus was reported also by Collinson and Banks (1975).

5.6. Ichnogenus Palaeophycus Hall 1847

Plates 122, 123. Figures 97A, 97B & 98.

5.6.1. Description and Preservation

Cylindrical or subcylindrical burrows. Preserved as convex hyporelief ridges beneath medium scale trough cross bedded sandstone, which is commonly underlain by thin mudstone unit. Apart from the form at Fletcher Bank Quarry (SD 806167, Plate 122) whose surface bears faint irregular transverse striae, the surface of the tube is generally smooth. The tube is sinuous, mutually intersecting and commonly branched (Plate 122). The dimensions are variable. For instance while the range of its length at Scout End Quarry (SD 944190) and Parkwood Quarry 2 (SE 070409) is 1cm to 9cm and 1cm to 2.2cm respectively (Figs. 99A & B), it is 4.3cm to 23.5cm at Fletcher Bank Quarry (Fig. 100, Plate 122). Similarly, the comparable diameter range of 1mm to 2mm at Scout End Quarry and 1mm to 2.5mm at Parkwood Quarry 2, ranges from 7mm to 20mm at Fletcher Bank Quarry. Burrow relief at the latter location is commonly 10mm. Though large, the size of these tubes in Fletcher Bank Quarry is not regarded as exceptional when compared with some of Hall's (1847) specimens reported by Osgood (1970, p.374). According to Osgood (1970, p.374), "the main branch (of Hall's Palaeophycus rugosum) has a diameter of nearly 3cm".

5.6.2. Location and Age, Facies and Sedimentological Context

Fletcher Bank Quarry (SD 806167); Age: Pule Hill Interval. Lithofacies 10, Trough Cross Bedded Sandstone of a Distributary Channel.

Parkwood Quarry 2 (SE 070409); Age: Pule Hill Interval. Lithofacies 10, Trough Cross Bedded Sandstone of a Mouth Bar Environment. Sandstone is medium-grained, quartzitic, micaceous and commonly underlain by thin mudstone unit.

Scout End Quarry (SD 944190); Age: Hazel Greave Interval. Lithofacies 10, Trough cross bedded sandstone of a Mouth Bar. Sandstone is medium-grained, quartzitic, well sorted and underlain by thin mudstone unit. The stratigraphic levels for these 3 locations are the same as was discussed in section 5.5.2. above.

5.6.3. Association

Planolites; Arthrophycus; Kouphichnium rossendalensis

5.6.4. Discussion

Probably burrow of Annelid worm. Annelids are usually characterised by cylindrical, smooth, branching, curved or sinuous tubes (Hallam 1970), as portrayed in Scout End Quarry (Plate 3), and Parkwood Quarry 2. The cross-cutting relationship between the load structures and Ichnogenus Palaeophycus at Scout End Quarry (Plate 3) indicates the post-depositional nature of the trace fossil. The latter is also regarded as interfacial based on the fact that it is horizontal and apparently parallel to the bedding plane in the 3 localities cited above. No particular significance is attached to its occurrence in both continental and shallow marine environments, because it is a common trace fossil which is not necessarily diagnostic of any particular environment (Osgood and Szmuc 1972, p.13).

5.7. Ichnogenus Pelecypodichnus Seilacher, 1953

Plates 98, 29, 124A, B & C, 125, 126A & B, 127, 128, 129, 130, 131, 132, 133.	Figures 59, 24, 16, 78B, 84-88, 77.

5.7.1. Description and Preservation

Preserved in the following 3 forms: elliptical hypichnial ridge (bulge or bump) on the lower surface (Plate 124A) or an oval epichnial groove on the upper surface (Plate 124B) or as endichnial vertical shaft (Plate 124C) consisting of V-shaped zones of disrupted laminations. Instances of the direct connections of the hypichnial bumps to the epichnial pits by the endichnial shafts occur and the best example seen which occurs in 3.5m level of the central vertical section of Fletcher Bank Quarry (Fig. 59) is shown in Plate 125. Endichnial preservation also occurs in the form of elliptical infillings of lighter coloured fine-grained sandstone, commonly with truncated top, within a darker coloured siltstone host (Plate 126A & B). Pelecypodichnus bumps are commonly smooth on the surface (Plate 124A), but also rough (Plate 128) often due to truncation (Osgood, 1970). Two broad size types of the hypichnial bumps are recognized. Type 1 is commonly 2 to 10mm long, 2 to 5mm wide, and often 2mm deep (Plates 126 & 129), and generally occur finer-grained sediment than type 2. Occasionally 'pin-point-sized' forms whose common length ranges from 1-2mm and width commonly 1mm occur either as epichnial pits on thin dark-grey mudstone lamina or as tiny bumps at the base of such mudstone. Such tiny epichnial grooves occur in abundance in 21-24m level (Fig. 24) of Warland Wood Quarries while the tiny hypichnial ridges were seen in Light Hazzles Clough mudstone (SD 956193) exposed from the Clough level to a height of 7m, and in Hodge Clough 25m level, g, Fig. 16) where it measures commonly 5mm long and 3-4mm wide. The common length of type 2 ranges from 10-20mm, with 5-10mm and 4-5mm deep though occasionally its length, width and depth of up to 30mm, 15mm and 20mm respectively occur. These unusually high dimensions occur in Fletcher Bank Quarry (3.5m level, central vertical section, Fig. 59; Plate 125) and in the 12m level (Fig.78B, Plate 127) of Harper Clough Quarry. Type 2 is more common by far than type 1.

The long axis of type 2 appears to have a preferred orientation

(Fig. 88) unlike type 1 which is randomly oriented (Plates 126 & 129). A similar observation was made by Baines (1977). Plots of the preferred orientation appear parallel to the palaeocurrent directions determined by scour marks and cross bedding (Figs. 84-88). Pelecypodichnus bumps also appear to exhibit marked variation in their manner of distribution, ranging from relatively isolated (Plate 124) to highly grouped (Plate 129) forms. In the grouped form, groups of 3 and up to 6 individuals may be aligned one behind the other, and often a faint ridge may connect these aligned types (cf. Lockeia Siliquaria, Osgood, 1970). In highly organized groups as in Scotland Flags and Foster Clough Quarries (SE 033268 and SE 021273 respectively) the individual bumps appear to align themselves along distinct zones which connect up to form polygons as suggested in Plate 130 (10m level, Fig. 77). The distribution in type 1 is commonly random (Plate 126A) sometimes with a remarkably high population density (Plate 129). The epichnial depressions were not as extensively exposed as the hypichnial bumps. Consequently the areal extent of the study of their distribution was far less extensive than in the case of the bumps.

In sections perpendicular to the bedding planes, endichnial tubes with vertical axes range from the short (10cm long) straight types (Plate 98), to the long (commonly 15-20cm long) straight varieties. The longest straight types seen occur in the 17-20m level (a, Fig. 15) of Brandshaw Quarry (SE 031402) and measures 35cm (Plate 131). The axis of the non-vertical shafts can vary from the slightly curved types (Plate 124C) to types that incline at 20-45^{o} from the vertical. This type is best shown in 7-8m (Plate 132) and 10-11m levels (Fig. 55) of Scotland Flags Quarry and their lateral equivalents in this figure. The maximum length of endichnial shafts measured in this study occurs in the inclined type in

Castle Carr Quarry (SE 028301) which measures 40cm long (Plate 133). Inclined tubes commonly show displacement (Plate 132). Tubes may be abundant (Plate 131) though not crowded, and have diameters that range from 3-25cm. Tubes may be funnel shaped (Plate 98) and the diameter of the widest upper parts of the funnels ranges from 1 to 45mm, tapering downwards to the diameter of their subjacent tube. The stratification phases of their host sediment surrounding tubes are deflected downwards towards the tube consequently destroying the stratification to various degrees (Plate 29). The most intense destruction of stratification is seen to occur in the 7-8m and 8-11m levels (Fig. 55) of Scotland Flags Quarry mentioned above.

5.7.2. Location and Age, Facies and Sedimentological Context

Widespread and common in lithofacies 2, 5, 6, 7, 8, 9, 10, 12, 14, 15 and 19, in all the three stratigraphical intervals, though most abundant in Pule Hill Interval. It is worth emphasising its occurrence in lithofacies 19, as such an environment is unusual for this ichnogenus.

5.7.3. Association

Olivellites, *Planolites*, *Kouphichnium*, *Cochlichnus*, *Arenicolites*, *Gyrophillites*, ?*Phycodes* *palmatum*.

5.7.4. Discussion

The hypichnial bump and epichnial depressions are generally believed to be the resting traces (Cubichnia) of small burrowing pelecypods (Seilacher, 1953; Osgood, 1970; Eager 1974; Häntzschel, 1975), while the endichnial shaft is thought to represent the dwelling structure

(Osgood, 1970). Hardy (1970b) regards endichnial tube as an escape shaft of a small bivalve and he believes that the structure forms when the mollusc moves through the sediment during deposition in order to stay in contact with the sediment-water interface. The fact that Anthraconia (Eager, 1974; McCabe, 1975b) and Carbonicola (Hardy, 1970b; Eager, 1974) are reported by these authors to occur on epichnial depressions and Carbonicola af. extentuata in depth position with escape shafts below in the Bullion Rock of the Lower Coal Measures of Lancashire (Hardy, 1970b) substantiates the escape shaft interpretation. The present author regards such tubes as both escape shaft and the course taken by the bivalve during its downward burrowing following Osgood (1970) and Eager (1977) as will be discussed later.

Seilacher (1953) and Hardy (1970b) contend that hypichnial bumps form when pelecypods press sand into the soft underlying sediment. Osgood (1970) is convinced that such bumps can be "casts of the foot" or "casts of the shell" of pelecypods or even casts of the burrowing pelecypod itself. In an attempt to reconstruct the origin of such bumps (that is, for Lockeia siliquaria) derived from the type locality, Osgood (1970) explains that the casts were initially formed and embedded on a mudstone unit prior to the deposition of the sandstone unit which they now occur under. The mechanism which he postulates can be briefly outlined as follows:

(i) Pelecypod burrows through the host unit, until it reaches the subjacent unit (a mudstone unit) which it nicks.

(ii) Pelecypod withdraws.

(iii) The host rock fills the holes made in the subjacent mudstone unit.

(iv) The host bed is eroded off, down to (but not into) the surface of the mudstone unit.

(v) Another silt bed was deposited, it underwent cementation, and the cast of the burrowing pelecypods were cemented to its bottom.

This postulate appears applicable to what might have obtained in the Central Pennine area during the Marsdenian times based on the following considerations. The unusually large bumps (some Type 2) are likely to represent casts of the burrowing pelecypod, probably the casts of the shell itself. The other two normal size classes may be the casts of the foot or the anterior portion of the valve. However, based on the different size types, all the forms may not be made by one species of pelecypod, unless the burrower started such activities at the spat age. The frequent abundance of bumps on the bases of mudstone units overlying mudstone or siltstone units appears to argue in favour of the above postulate. Also, such mechanism explains the genesis of grouped and organized forms as close burrowing activity on the underlying nutrient rich sediment surface can produce such a pattern.

The displacement of the axis of some of the inclined shaft may be indicating stages in the influx of the delta sediment (cf. Eager 1977), probably forcing the bivalve to jump from one axis to another (Eager, personal Comm., October, 1980), during its upwards escape. The long endichnial tubes are probably indicating areas of unusually active sedimentation which provided comparatively thick sediment piles, based on the assumption that vertical extent of the shaft reflects rapid sedimentation, during which time the bivalve had to move quickly upwards to survive orburrow deeply down to avoid such ecological stress like salinity changes, fluctuations in temperature and strong currents (cf. Crimes 1975; Baines, 1977).

The most prominent observation is the wide range of palaeoenvironments, ranging from the Slope Association to the Delta Top Assemblage including even seatearths, characterised by Pelecypodichnus as is shown in section 5.7.2. It is noteworthy that Pelecypodichnus occurs in the prodelta mudstone interpreted by Wright et al., 1927, and verified by the present writer as marine, implying the wide salinity range of Pelecypodichnus of this study. Such occurrence argues in favour of the suggestion that all the forms of Pelecypodichnus of the Marsdenian sediments may not have originated from one species of pelecypod.

Hardy (1970b) contends that the presence of interbedded siltstones or mudstones in a sequence provides a more favourable environment for Pelecypodichnus against a situation with purely sandy beds, while this observation applies to the area of study, the trace fossil also occurs in thick sandstone. However, in many of these cases particularly in thick channel sandstone, it often appears to originate in zones of comparative quiescence and to have risen into the overlying coarser sediment during periods of faster sedimentation (cf. Eager et al., in press).

5.8. Ichnogenus Phycodes Richter 1850

Phycodes cf. curvipalmatum Pollard (1981)

Plates 134, 135. Figures 99, 100.

5.8.1. Description and Preservation

Horizontal, ramifying, tube-like, interstratal burrows preserved as ridges on the undersurface (convex hyporelief) of a poorly sorted sandstone which is 5-8cm thick. The proximal part of the tube is straight, or gently curved, occasionally portraying annulated structure suggestive of spreite-like internal packing (Plate 133, Fig. 99). In section the burrow is subquadrate or squarish. The tube can be unilobed, bilobed or rarely trilobed. Tube length of 13cm and more occur, but lengths of about 4cm are common. Common tube diameter is 3-5mm, but diameter range of 1-6mm also occurs. The burrow relief at the proximal parts ranges from 1-7mm. Generally there is an intense cross-cutting of the burrows, locally giving the fossil a net-like pattern. 2 types of distal termination of the tubes are apparent: the "palmate" and the "ovoid" forms. The "palmate" type shows either a Y-shaped branching form where either branch of the Y fans out in a petalloid manner ("A") or simple finger-like branches radiating off a common tube ("B", "B1"). The diameter of the distal part is commonly 12mm, and the relief 5-7mm. The distal branches recurve both laterally and upwards into the overlying sandstone ("A", "A1"). The short diameter of the "ovoid" structure ranges from 5-8mm, the long diameter 8-14mm and the relief 3-8mm ("C"). Burrows with the palmate terminal parts can occur both solitarily ("A") and in an intimate overlying relationship with one another. Locally, the branches and intersections of the burrow can appear to radiate outwards from a common point ("E"). The "ovoid" types appear to occur only in solitary form. Generally, this trace fossil is morphologically identical to the <u>Phycodes curvipalmatum</u> ichno sp. nov. of Pollard (1981). Some resemblance to ichnogenus <u>Fucusopsis</u> may be noticed in this trace fossil at such proximal straighter parts that are apparently unpacked. Also a resemblance to ichnogenus cf. <u>Arthrophycus</u> occur where spreite packing approaches annulation (F). A resemblance to cf. <u>Nereites</u> occurs where compression of spreiten packing has produced an apparent series of lateral lobes (arrowed in Fig. 100 & Plate 135).

5.8.2. Location and Age, Facies and Sedimentological context

Wicking Crag Quarry 2 (SE 052372); Age: Hazel Greave Interval. "Scour based", medium scale trough cross bedded sandstone of a Distributary Channel. Sandstone is coarse- to very coarse-grained, poorly sorted, feldspathic, micaceous and rich in wood fragments and coal. "Scour based" sand bodies are commonly 1-5-5m thick, 23-30m wide. Each sand body constitutes a coset, with common trough thickness of 5-40cm and trough width of 0.50-3m. Cosets are separated by easily eroded interbeds of sandstone commonly 3-24cm thick. Ichnogenus Phycodes of curvipalmatum occurs at the base of one of these cosets.

5.8.3. Association

?Arthrophycus

5.8.4. Discussion

Fodinichnia of a sediment feeder, exploiting the food rich mudstone underlying the sand body. The palmate distal branches are regarded as the casts of trails progressively made by the organism as it fed. Osgood (1970, p.100) contends that the producer of a comparable palmate branching, first mined out one trail, pulled back and made the second one adjacent to the first. He believes that such a process was repeated several times, probably as many times as there are branches. Perhaps in response to an increased sedimentation, the organism may tend to rise to avoid burial. It did so probably with the long axis of its shell vertical. In this vertical position, its foot may still be in contact with the underlying mudstone. If so, some of the ovoid bodies beneath the sandstone probably represent casts of a foot (Osgood, 1970, p.310), while others may be the casts of any accompanying steep burrowing as in ichnogenus Pelecypodichnus.

This view on the genesis of the trace fossil appears supported by the fact that burrows of a palmate branching type known from Buntsandstein in Germany, are associated with a marine bivalve (Pollard, 1981, , p.24). Association of trails with ovoid or palmate ends may suggest that the two parts of the trace fossil may represent different behavioural patterns of the same organism (Pollard, 1981, , p.25).

5.9. Ichnogenus Phycodes Richter 1850

?Phycodes palmatum Hall

Plate 119. Figure 96.

5.9.1. Description and Preservation

Convex hyporelief at the base of a medium-grained quartzitic, well sorted sandstone underlain by thin mudstone unit. A raised elongated mound composed of smaller conical mounds of radiating lobes which are pointed distally where they disappear into the bedding plane. Elongated mound was probably cross-cut by the southern loop of the associated meandering ichnogenus Cochlichnus into specimens 4 and 5. Specimen 4 is 75mm long and 56mm wide. Specimen 5 is 42mm long and of equal width with specimen 4. Elongated mound closely resembles radially disposed Phycodes palmatum although considerably larger.

5.9.2. Location and Age, Facies and Sedimentological Context

Parkwood Quarry 3 (SE 067406); Age: Pule Hill Interval. Trough cross bedded sandstone of a Distributary Mouth Bar. (For more details of this environment refer to the section on Sedimentological context under ichnogenus Gyrophillites).

5.9.3. Association

Cochlichnus, Gyrophillites, Pelecypodichnus, Olivellites, Planolites.

5.9.4. Discussion

Fodinichnia of a probable wormlike organism. Based on its sedimentological context, this ?Phycodes palmatum may be a shallow water type.

5.10. Ichnogenus Planolites Nicholson, 1873

Plate 136. Figures 97A, 97B.

5.10.1. Description and Preservation

Cylindrical to semi-cylindrical infilled burrows. Preserved as both interstratal epirelief and hyporelief ridges. Lies dominantly parallel to bedding plane. Smooth walled and non-branching. However, occasionally some of the traces criss-cross one another in such a manner that one burrow lies on an earlier one consequently appearing branched. Heinberg (1970) reported a similar observation. At Parkwood Quarry 2 (SE 070409), groups of small straight burrows bunch together intimately as in Chamberlain's (1971) Plate 31, Fig. 4, so that it becomes difficult to decipher whether they are branched. Planolites of this study occurs either in a small size range of length 5-25mm, diameter 1-25mm or in a medium size range of length 26-80mm, and diameter 3-5mm (Plate 136). Planolites can be preserved as a ridge both epichnially and hypichnially.

5.10.2. Location and Age, Facies and Sedimentological Context

Parkwood Quarry 2 (SE 070409); Age: Pule Hill Interval. Medium scale trough cross beds of a mouth bar (same as in ichnogenus Palaeophycus).

Parkwood Quarry 3 (SE 067406); Age: Pule Hill Interval. Trough cross bedded sandstone of a Distributary Mouth Bar (same sedimentological context as Ichnogenus Gyrophyillites).

Scout End Quarry (SD 944190); Age: Hazel Greave Interval. Small scale trough cross bedded sandstone of a Mouth Bar (same sedimentological context as Ichnogenus Palaeophycus).

Rake Dike (SE 098051); Age:Scotland Flags Interval. Parallel stratified siltstone of a turbidite unit. Unit is 1.6m thick and occurs about 8m above the underlying marine band. The first significant influx of Mouth Bar sediments occur about 15m above the turbidite unit. (Trace occurs as interstratal burrows).

Cowloughton Clough (SD 966412); Age: Pule Hill Interval. Medium scale trough cross bedded sandstone of a Channel Abandonment Facies. Sandstone is medium grained, and overlain by 20cm thick organic rich mudstone. (Trace occurs as ridges on the sandstone unit underlying the organic rich mudstone).

5.10.3. Association

Palaeophycus, Arthrophycus, Kouphichnium rossendalis, Gyrophillites, Pelecypodichnus, Cochlichnus, ?Phycodes palmatum.

5.10.4. Discussion

Regarded as infilled burrow "which worm has passed through its alimentary canal" (Nicholson 1873). Occurs dominantly as interfacial burrow and occasionally as surface trace. The intersection of the scour marks by the small branches of this trace fossil at Parkwood Quarry 2 indicate their post-depositional origin at that location. That this trace fossil should occur in the various lithofacies mentioned above is an evidence of its known facies-crossing ability.

5.11. Ichnogenus Olivellites plummeri Fenton & Fenton (1937)

Plates 126, 137, 138A, 138B, 139, 140, 141, 142A & B. Figure 17

5.11.1. Description and Preservation

A meandering trail preserved as both epichnial, hypichnial and endichnial groove and or ridge commonly in fine to medium-grained, clean, well-sorted sandstone. The trails vary both in sinuosity, in population density, in length and width and in cross sectional thickness. Based on population density and degree of sinuosity the 2 types seen range from the solitary, mildly sinuous forms (Plates 126 & 137) to the grouped, complexly meandering variety. The latter type characterises all localities, excepting Rake Dike (SE 100052, Plate 126) and Readyshore Scout Quarry (SD 942198, Plate 137). A recommended type locality for the grouped form is Ponden Clough (SD 980364, 35.24-35.64m level, sequence f, Fig. 17) because it is developed best there. Marked undulation of the trails in this Clough (Ponden Clough) can be both in horizontal (Plates 138A & B) and vertical (Plate 139) directions, occupying a thickness zone of some 40cm (Plate 140) and traceable in outcrop continuously for up to 15m before being lost to cover. The meander path here is characterised by abrupt sharp turns of up to 90^{o} and doubling back, sometimes continuing back along its previous path and sometimes crossing over (Plates 138B & 139) its previous path due to its high sinuosity (cf. Yochelson & Shindel, 1978). It is clear also from Plates 139 and 140 that the traces appear to align themselves along the same horizontal level. Plates 139 (a polished vertical section perpendicular to the bedding plus some top plane) and 140, a similar vertical section (minus the top plane) and 140, a similar vertical section (minus the top plane) whose picture was taken at the outcrop, portray promently the colour contrast between the cast infilling of this trace and the host rock. This is because while the infill sandstone is very light grey in colour, the host rock is light grey. Also, in thin section, while the cast is medium grained, clean and well sorted the host rock is fine- to medium-grained and moderately sorted. Even though several features of this trace fossil are equally distinct in some other localities. For instance, the crossing over activity is prominent in Bare Clough (Plate 141) which also exposes other features such as a ridge-like medial cord and fine transverse ridges on the body of the trace. Distinct groove-like counterpart of medial cord similar to the one in Plate 142B occurs in Gorpley Clough. The features of Olivellites exposed some 6m below the R. gracile band in Rag Clough (22-25m level, Fig. 20) were studied to see how they compare with those of this study. They (Plates 142A & B) portray very similar meander style as described above and clearly show the ridge-like medial cord (Plate 142A) and the groove-like counterpart (Plate 142B). In general, the morphological features of the trace fossil of this study are identical to those of Olivellites plummeri collected from its type locality in Eastland County, Texas, and described by Yochelson & Schindel 1978. The degree of this similarity is better appreciated by comparing the distinctive features of Olivellites plummeri listed by Yochelson & Schindel with those of this study as is done below.

Distinctive Features of Olivellites plummeri

Yochelson & Schindel, 1978	This study
(i) Presence of a thick medial cord on the upper surface of the trace.	Same (only in Bare Clough).
(ii) Width of medial cord varies from 1.5-2.5mm.	Same (Gorpley Clough).
(iii) Width of trace varies from 15-25mm commonly 20-23mm.	Width ranges from 6-15mm, rarely 20mm (Plate 139).
(iv) Cross section of the trace is a low flattened ellipse, the medial cord extend above the highest part of the ellipse.	Same (Plates 139 & 140).
(v) No differentiation of grain size between the trace and the host rock.	Differentiation of grain size occurs commonly.
(vi) Fine transverse ridges present.	Seen occasionally.
(vii) Band surface of the trace featureless, bears neither transverse ripples nor any medial depression or elevation.	Same.

5.11.2. Location & Age, Facies & Sedimentological Context.

Because of the numerous locations involved, the lithofacies will be represented by their lithofacies number notations.

1.	Tower Hill Side (SD 907261)	R2c,	Lithofacies	9	.....	Mouth Bar
2.	Ramsden Clough (SE 12203b)	R2b,	"	9	.....	Minor Mouth Bar
3.	Warland Wood Quarries (SD 948202)	R2b,	"	8	.....	Crevasse Channel
4.	Rake Dike (SE 098051)	R2a,	Lithofacies	19	.....	Turbidite
5.	Parkwood Quarry 3 (SE 067406)	R2b,	"	14	.....	Mouth Bar Area
6.	Bare Clough (SE 019309)	"	"	14	.....	Mouth Bar
7.	Gorpley Clough (SD 918236)	"	"	14	.....	" "
8.	Lead Mine Clough (SD 964160)	"	"	14	.....	
9.	Owler Clough (SD 947196)	"	"	14	.....	" "
10.	Readyshore Scout (SD 943197)	"	"	14	.....	" "

11.	Harper Clough Quarry (SD 717318)	R_{2b},	Lithofacies	14	....	Mouth Bar
12.	Ponden Clough (SD 980363)	"	"	14	....	" "
13.*	Rag Clough (SE 014338)	R_{1c},	"	14	....	Minor mouth bar

(*Rag Clough data was put in for comparison purposes only. Its stratigraphic level is outside the scope of this study). It is worth noting the preference of this trace fossil for mouth bars).

5.11.3. Association

The only trace fossil seen in the same bedding plane with Olivellites of this study is Pelecypodichnus, as occurs spectacularly in Rake Dike (Plate 127), but also in Tower Hill Side and Warland Wood Quarries. It is noteworthy that Yochelson & Shindel reported that the only trace fossil they found in the same bedding plane with Olivellites in the type locality are "simple vertical tubes, both straight and slightly curved, that have a diameter of about 1cm". This tube may be the endichnial tube of Pelecypodichnus. It is worth emphasising the fact that traces of Pelecypodichnus cross cut those of Olivellites in Rake Dike.

5.11.4. Discussion

Yochelson & Schindel suggest (1978) that Olivellites may be the crawling traces (Repichnia) of probably isopods and that the medial ridge may represent the trace within the sediment of a raised dorsal ridge on a carapace of such an animal. This interpretation is acceptable to the writer based on the features of the traces of this study as discussed above. Also similar to Yochelson & Schindel's interpretation is the environment of deposition of this trace fossil, which they contend to be a "shallow subtidal setting". Although a tidal environment is ruled out for the Central Pennine Basin (see Coastal Factor, Chapter 6) a shallow water setting appears favourable to producer. It appears that the mouth bar environment is their most conducive setting as suggested by 5.11.2. Its occurrence in the Crevasse Channel setting at Warland Wood Quarry and in the Prodelta turbidite and of Rake Dike appears to suggest that the mode of deposition of their host sediment giving sand and mud or siltstone interfaces also exert some control in their distribution.

Its alignment along distinct horizontal levels (Fig. 140) suggests that it followed some defined depth within the substrate as it crawled.

5.12. Ichnogenus '<u>Scolicia</u>' De Quatrefages, 1849

Plates 143A & B.

5.12.1. Description and Preservation

Meandering burrows preserved as sand infilled, epichnial ridges on the top surface of a medium-grained, quartzitic well sorted sandstone interbedded with mudstone. The common diameter of the sinuous tube ranges from 2 to 5mm. Most tubes (if not all) are enlarged into a protuberance at each end (Plate 143A). However, some appear to have such bulge only at one end. The common diameter of the ephenial protuberance is 10-15mm. The common range of length of the sinuous burrow measuring through the sinuous course is 42-150mm, but the maximum length measured along such a coarse ranges from 200-300mm. The intensity of sinuosity is mild and the turns have gentle curvature, however, crossing over of one trace over another occurs (Plate 143B).

5.12.2. Location and Age, Facies & Sedimentological Context

Park Wood Quarry 3 (SE 067406); Age: Pule Hill Interval. Lithofacies 10, Trough Cross Bedded Sandstone of a Mouth Bar area (same sedimentological context as Ichnogenus Cochlichnus discussed in section 5.3.2.).

5.12.3. Association

Pelecypodichnus

5.12.4. Discussion

These traces compare very closely with the 'Scolicia' obtained from the Standedge Cutting (R_{1c}) which were illustrated and described by Eager, Okolo & Walters (in press) who interpreted them as of gastropod origin. Scolicia is regarded as creeping or feeding burrow (or both) of gastropods (Häntzschel, 1975).

5.13. Ichnogenus Zoophycos

Plates 144A, 144B.

Description and Preservation

Large star-like impression preserved as indichnial relief and at least 20cm in diameter (edge not seen on the specimen). The structure is conical and has an axial apical tube. The apex is polygonal. The longer diameter of the apex is 2cm. The shorter diameter is 1.5cm. Its relief from the flat distal surface is 5mm. About 35 rays (lamellae) radiate downslope from the sides of the apex (Plate 144B). 4cm downslope from the apex, the lamellae flatten, bend in a helical spiral and show distinct distal bifurcation. Width of each lamellae ranges from 2-4mm. A prominent radial structure (arrowed in Plate 144B), compressed vertically and 4mm wide near its proximal origin (measured on the hypichnial fracture of the endichnial burrow core) appears to be a discrete tube (marginal tunnel cf. Simpson 1970, Fig. 1a). This tube curves from the apex to the periphery. Within the sediment, this specimen shows laminae with spreiten varying in direction between layers. The total depth of the Zoophycos structure is greater than 5cm, although hard to confidently ascertain as it is composite.

5.13.1. Location and Age, Facies and Sedimentological Context

Junction of Ponden Clough tributaries (SD 981365); Age: Pule Hill Interval. Bluish grey, micaceous silty mudstone, rich in anchoring spines and spicules of the sponge Hyalostella smithi (Stephens et al. 1953, p.103) and known in the area as "Bluestone". Lithofacies is integrated as a low energy shallow marine sediment with evidence of current incursions activity.

5.13.2. Association

None.

5.13.3. Discussion

Feeding structure of an unknown wormlike animal that lived probably in a shallow marine area. Such a complex fodinichnia is considered a product of a discontinuous process (Simpson 1970, p.511) involving the successive tunnelling of a series of feeding tubes one after the other. Though usually regarded as characteristic of deep water facies, (cf. Seilacher's (1967) bathymetric zonation) Ichnogenus Zoophycos appear to have a considerable depth range and may occur wherever the surface sediment was largely undisturbed by waves, currents or profound bioturbation (Hallam

1975). It can even be found in such shallow areas that are above wave base (Osgood and Szmuc 1972). Indications of the extent of shallowness of the Ichnogenus Zoophycos environment of this area are provided by the following evidence observed at Ponden Clough (SD 981365).

(i) 11 metres above the "Bluestone", 5.6 metres of bioturbated sandstone overlain by coal occurs.

(ii) The siltstone lithosome in the "Bluestone" occurs as lenticles which connect to form composited pinch and swell bands. Analogous siltstone geometry occur in Meadville and Armstrong members in Northern Ohio, also rich in Ichnogenus Zoophycos and interpreted similarly as above by Osgood and Szmuc, 1972.

Kennedy (1975) reported the occurrence of Ichnogenus Zoophycos "in siltstones alternating with coals and rootlets beds in the Yoredale Facies of North England .....". Hecker (1970) documented a shallow water habitat for the ichnogenus Zoophycos of the Russian platform.

These documented occurrences support the fact that an interpretation of shallow marine as an environment for Ichnogenus Zoophycos is not unique to this place.

Ichnogenus Zoophycos of this area is probably of the Spirophyton type (cf. Ichnogenus Spirophyton recommended by Simpson, 1970), based on the presence of central cone, helical curvature, and compressed axial margin. However, the thorough bioturbation of the host rock together with the small size of the specimen do not rule out Zoophycos cauda-galli type.

5.14. Loop & Sinuous Trails

Plates 145, 146A & B.

5.14.1. Description and Preservation

Preserved as a cylindrical epichnial ridge (Plate 145) or tube like endichnial ridge (Plate 146A) or groove (Plate 146B) in a medium grained sandstone. They can be sinuous and so are termed sinuous trails (Plates 146A & B) or loop-like and called loop trail (Plate 145) with one end of such loop enlarged into a protuberance Their common width ranges from 1 to 3mm.

5.14.2. Location & Age, Facies & Sedimentological Context.

Loop-Trail: Fletcher Bank Quarry; R_{2b}; Trough Cross Bedded Sandstone within Channel 2.

Sinuous-Trail: Light Hazzles Clough; R_{2b}; Siltstone of a Mouth Bar.

5.14.3. Association

Pelecypodichnus

5.14.4. Discussion

Based on their geometry they are regarded as infilled trails.

5.15.1. Distribution of the Trace Fossils in the Marsdenian Sediments.

The distribution of the trace fossils with regards to the overall stratigraphical sequences in the 3 intervals is illustrated in Figure 101. The most prominent observation is the wide variation in the range of ichnogenus Pelecypodichnus, which ranges from the R_{2a} Prodelta turbidite through the R_{2a} mouth bar area to the delta top areas, with a comparable range in the Pule Hill interval. Ichnogenus Planolites is also shown to tolerate a wide range based on the fact that its few occurrences spread to these two broad associations. Olivellites is not considered to show a wide range based on the number of localities involved and marked preferential occurrence to mouth bars. Its spread to the Prodelta and to the Interdistributary settings are anomalies explainable in the context of the influence of some certain factors which will be mentioned later.

Another observation is that the Scotland Flags Interval, particularly the Slope Association is generally devoid of trace fossils except the 3 mentioned above. There is also a general lack of trace fossilsin the lower parts of the Slope Association of the Pule Hill Interval, except for the lone occurrence of the Zoophycos at the Prodelta area of Ponden Clough, and the lone Pelecypodichnus in Light Hazzles Clough, but the diversity increases in the coarser lithofacies sub-association, that is, the Mouth Bar areas. This increase is carried over into the delta top Assemblage and particularly within the Interdistributary Complex Association. Again trace fossil decreases in the Hazel Greave Interval, however, insufficient sampling due to lack of exposure may account for the apparent paucity at this interval.

The only slope trace fossil of the Scotland Flags Interval is limited to the Pelecypodichnus at Rake Dike and Wessenden Reservoir areas. The Rake dike traces are endichnial while that of Wessenden are hypichnial, directly on top of a unit of Lithofacies 5, Mudstones and Siltstones. In both the Mouth Bar and Delta Top areas where the abundance and varieties of trace fossils is greatest, individual trace fossils appear to be associated with zones of interbedded siltstones or mudstones in the sequences, as was discussed in the section for these individual fossils.

5.15.2. Interpretation

Seilacher (1967) postulated the theory that trace fossil communities are mainly bathymetry-controlled. He erected a scheme involving the following major communities (listed in order of increasing depth, where number 1 is the deepest).

6.	Scoyenia	Non Marine
5.	Skolithos	Littoral Marine
4.	Glossofungites ...	Littoral
3.	Cruziana	Infra LIttoral to Circa Littoral
2.	Zoophycos	Circa " " " Bathyal
1.	Nereites	Bathyal to Abyssal

The above scheme depends on the assumption that turbulent environments (shallow water) will exhibit vertical burrows of suspension feeders, whilst deep water environments will show predominantly horizontal trails of deposit feeders (Seilacher 1967, Ager & Wallace 1970).

Except for the Olivellites which appears to be relatively depth controlled, no other trace fossil or trace fossil assemblage can be assigned to Seilacher's bathymetric ichnofacies. The extensively wide range of Pelecypodichnus and Planolites demonstrates this non-adherance best. Hakes (1976) contends that the entire trace fossil assemblage must be taken into consideration and not just one member. The assemblage of Ichnogenera Gyrophyllites, Cochlichnus, pelecypodichnus, Kouphichnium rossendelensis, ?Phycodes palmatum in one bed is most inconsistent with any bathymetric zonation. Also the depth range of Zoophycos of this study is far from the intermediate depth range meant for it in the zonation. This discrepancy may be due to the fact that the idea of a marine basin on which Seilacher's (1967) model was built does not necessarily apply in the Central Pennine Basin during the Marsdenian period. Furthermore, the whole basin filling during the progradation of the Marsdenian delta took place in a comparatively shallower depth of water than the one for which Seilacher (1967) model was constructed. It appears that what exercises a significant control on the distribution of the Marsdenian Stage trace fossil is the mode of deposition which provided sand and siltstone or mudstone unit (cf. Eager et al., in press). The fact that the Prodelta turbidite of Rake Dike, for instance, is richer in trace fossil than those of Wessenden is explainable by Crimes' (1970) contention that the preservational potential in turbidites increases with a more distal aspect. In Rake Dike, more finer-grained interbeds occur than in Wessenden giving a more distal aspect of the former deposits (see section 4.2.2.1.). The influence of the mode of deposition factor is better seen in the Mouth bar and the Interdistributary sediments of the Pule Hill Interval where the greatest abundance and diversity of the trace fossils occur. The Gyrophyllites, Scolicia, Palaeophycus, Planolites, Kouphichnium and Cochlichnus and ?Phycodes palmatum are all associated to the sandstone/ mudstone interbeds where they have been seen to occur at the basal part or top part of either the two beds with a parting in between them. The occurrence of Horizontal Bedded Sandstone which are usually medium-grained appear to have been favourable to the fossils, particularly Olivellites whose maximum number occur in them. Probably they were rich in nutrients or had thin mudstone partings which contained the food they need. The only occurrence of this fossil in the Crevasse Channel is associated with zone of discharge variation. In the delta top areas the Arthrophycus, Palaeophycus, Phycodes curvipalmatum, Arenicolites are similarly associated with zones of sandstone/mudstone interbeds. Even in the channels that have thick sandstone units, the fossils are often associated with beds recording discharge vatiations. Pelecypodichnus, particularly is associated with zones of relative quiescence or comparatively low energy, but faster sedimentation forces it upwards to escape burial.

CHAPTER 6: BASIN ANALYSIS AND SYNTHESIS

6.0. Introduction

This final chapter discusses palaeocurrents and the major factors thought to have controlled sedimentation. The chapter hopes also to synthesise all relevant data from the previous chapters particularly those chapters on Lithofacies/Assemblage and on lithology in the reconstruction of the Marsdenian palaeogeography, delta type and morphology in the Central Pennine Basin.

6.1. Palaeocurrents

6.1.1. Introduction and Method of Study

Directional structures treated here are those thought to be related in some way to the currents system prevailing at the time of the sediment deposition and which are considered to be fossil record of such palaeocurrents. The directional structures of this study, already briefly treated in Chapter 4, and which are considered here as reliable include the following:

(i) Groove casts and other tool marks.

(ii) Scour marks, especially flutes but also longitudinal furrows and ridges.

(iii) Primary current lineation.

(iv) Cross bedding, involving trough axis bearing, foreset dip directions and ripple flow directions.

As regards trough cross bedding (that is part of iv above) where a set or coset consists of a mixture of tabular and trough cross beds, directional structures from trough axis bearings were preferred to foreset dip direction, and in no case were the data derived from both plotted together as results got from combined plots are never reliable (High & Picard, 1964). Trough axis bearing are considered more reliable (in terms of less dispersion) and more economical (with reference to less required measurements) indicators of palaeocurrents (High & Picard, 1964). The trough axis bearing and the ripple flow direction derived from the curved closures of the set margin as exposed in plan (plates 27, 38 & 86) are regarded as very reliable, though the foreset dip directions of trough cross-strata were also measured where they were well exposed in three dimensions. Foreset dip directions of Tabular Cross Bedded Sandstone were also measured where they were well exposed in three dimensions. Plants and Pelecypodichnus hypichnial or epichnial traces are also utilized in this study in palaeocurrent investigation, following Pelletier (1958), Bluck and Kelling (1963) and Mayhew (1967) in connection with plants and Hardy (1970) with regards to Pelecypodichnus.

The direction of elongation of Pelecypodichnus was determined commonly from the lower bedding planes of sandstone where they are exposed as oriented elliptical ridges, or occasionally from the upper bedding planes where they occur as elliptical hollows. In each case the direction of elongation of each Pelecypodichnus was determined by aligning the compass parallel to their elongated axis. Orientations of plants were measured in a similar way to the Pelecypodichnus, mostly from the upper bedding planes though also from the base.

Where necessary the directional readings have been corrected for structural dip on the stereonet by rotating the individual readings around an axis parallel to the structural strike by an amount equal to the angle of the structural dip, according to the method described by Potter and Pettijohn (1963). The determination of structural dip was often easy as some beds in most locations of the study area were commonly deposited near horizontal. Generally, therefore, dips of lithofacies 14, Horizontal Bedded Sandstone; 9, Parallel Laminated Sandstone; 8, Trough Cross Laminated Sandstone and even 1, Unfossiliferous Mudstone (stratified types) or 2, Fossiliferous Mudstone were frequently considered as the structural dips of the area. However, in an exposure showing only tabular sets of cross-beds, the structural dip was obtained by measuring the inclination of the planar surfaces between the individual sets, following Mayhew (1967). However, these dips were treated with caution as these planar surfaces may after all be of erosional origin, and not necessarily horizontal at the time their adjacent overlying material accumulated. In an attempt to obtain fairly accurate structural dips, the surfaces between markedly wedge-shaped sets or inclined sets were avoided and any adjacent sandstone unit portraying any of the reliable lithofacies mentioned above were used.

6.1.2. Treatment of the Palaeocurrent Data

In order to portray the general picture of the palaeocurrent flow for the overall Marsdenian sediments, the palaeocurrents for the Scotland Flag-, Pule Hill-, and Hazel Greave Intervals were plotted together in the form of rose diagrams on the Ordnance Survey 1:50,000 topographical maps sheets 103, 104, 109 and 110). Different colour notations were used to distinguish the various chronostratigraphical intervals. For practical reasons, it was not possible to incorporate the plots of all the locations because the readings from adjacent localities overlapped on the map. Plots of most localities are included. However, plots of the orientation of plants and Pelecypodichnus are excluded and rather plotted differently as discussed below. The result of the plot of these three chronostratigraphical intervals are shown in Figures 84A & 84B. The palaeocurrent flow for the individual intervals are separately plotted in Figures 85 to 87 for clarity. However, in plots 85 to 87, the midpoint of the modal classes was preferentially plotted, following the recommendation of Potter and Pettijohn (1963), because of its convenience for a regional survey of this nature, as it allows the plot to be positioned at the specific locality of derivation in contrast to current rose. Each midpointplot is regarded as a "point-estimate, a specific direction rather than an interval estimate, of average current direction" (Potter & Pettijohn, 1963). The point estimate approach was also adopted in the plot of the orientations of the plants and Pelecypodichnus shown in Figure 88. In all these plots, readings of orientation data are grouped in 15^{o} class interval, while the readings of data showing specific directions of movements are grouped in 30^{o} class following Potter and Pettijohn (1963).

Palaeocurrent data are presented also either in the left or right side of several of the vertical sections (Figs. 12, 14-17, 24, 56, 59, 68) depending on the availability of space.

As seen in Figures 84A & B, the rose diagrams are generally unimodal, and often symmetrical about the mode. The rose-, and mid-point diagrams (84-87) generally show modal classes indicating that there is some variation in character of the palaeocurrents between adjacent areas. For instance, during the Scotland Flags Interval while most localities in areas 1, 2 and 3 (Fig. 84A) show palaeocurrent flow to the southwest or southeast, a few localities such as Diggley Quarry (SE 110074), Riddlesden Quarry (SE 068430) and Derry Hill Quarry (SE 166435), portray strong elements towards the north. Similarly, during the Pule Hill Interval, while the dominant flow is again either to the southwest or southeast, the components towards the north are seen at Park Wood Quarries (SE 067406 & 070409), River Laneshaw (SD 954405), and Cowloughton Clough (SD 966410). In Hazel Greave Interval, flow towards the north is only shown in Clough Road exposure (SE 083158). The variable consistency in palaeocurrent flow-direction is also visible in many individual outcrops where the exposure of good thickness of the sandstone occurs especially over a large lateral extent as is illustrated in the 3 vertical sections made in Fletcher Bank Quarry (Fig. 59). In general therefore, within this framework of variation over the region, there is an overall dominance of northeast to southwest but also northwest to southeast palaeocurrent flow.

The palaeocurrent trend indicated by the plants and Pelecypodichnus are also consistent with this northeast to southwest and northwest to southeast direction (Fig. 88). Examination of the arrows for the plant stem or Pelecypodichnus orientation shows that the modal class of each locality lies generally near the scour marks or cross-stratification's modal class for the equivalent locality, though it is rarely coincident with it. This may be accounted for by inadequate sampling. In addition however, it must be remembered that the formation of a plant or Pelecypodichnus covered surface is probably attributed to a discrete phase of deposition, as is a solitary set of cross-strata. Variation in current flow direction between sets is clearly seen from the widely varying cross-strata dip directions and the Pelecypodichnus and plant covered horizons merely testify to directional and velocity changes.

It is clear from this study that plant fragments and Pelecypodichnus can be used as reliable indications of current flow directions provided sample sizes are large enough.

6.1.3. Interpretation

The results of palaeocurrent analysis show positively that the Marsdenian sediments have been deposited by currents which in general flowed from north to the south, dominantly northeast to southwest. This conclusion is in consonance with those of Sorby (1858) and Gilligan (1919) and several other workers mentioned in section 1.5.

The variations mentioned above are regarded as probably local changes in direction of flow of the depositional currents. The sandstones at different localities were deposited by palaeocurrents which were broadly unidirectional and only mildly variable in direction is shown by Figures 84 to 88.

6.2. MAJOR FACTORS CONTROLLING SEDIMENTATION

6.2.0. Introduction

The factors thought to have controlled the sedimentation of the Marsdenian Deltas of Central Pennines are discussed below under the following 5 broad headings.

(i) River processes factors

(ii) Coastal processes factors

(iii) Structural behaviour factors

(iv) Climatic factors

(v) Salinity factors

6.2.1. River Processes Factors

Effects of the river factor are prominent right from the Deep Water Association through the Slope Association to the 3 Associations within the Delta Top Assemblage, as discussed below.

Deep Water & Slope Associations: In the Deep Water Association, the turbiditic channel fill deposits discussed in section 4.1.1. indicates the influence of the distributary channels which they are thought to have linked back to the source of their coarse sediments. The Prodelta turbidites of the Slope Association also furnish evidence of the Fluvial Process. These turbidites are considered as products of sediment-laden discharge issuing from the distributary mouth areas during flood period in the manner discussed in section 4.2.2.1. The unidirectional character of the sole marks may also be an evidence in support of a fluvial influence.

Delta Top Assemblage: That there as a significant river influence at the delta top area is suggested by the variations both in the sediment load and in the transport capacity of the distributary channels. The erosional bases of many of these channels are frequently characterised by lag concentrates composed variously of logs of wood (Plates 43, 66, 67, 105 & 106)some of which are coalified (Plate 71), quartz and mud conglomerates (Plates 68, 69, 78C & 107), pebbles (Plates 87A & D). Large blocks of sandstone and siltstone also characterise the erosional bases as discussed in section 4.3.1.1. The infill sediments themselves are often medium-grained to coarse-grained sometimes pebbly sandstone. It is felt that the passage from these types of erosional bases through massive beds and large scale cross bedding to other lithofacies of low energy level as is shown in Table 19 represent a net waning of the maximum flow regimes developed by the highest flood as obtains in the Brahmaputra (Coleman, 1969). The reactivation surfaces within the large-scale cross bedding discussed in section 4.3.1.1. are further evidence that the river discharge fluctuated substantially, thereby generating low river stage and its consequent low stage modifications to bedforms.

It may be relevant to this discussion to expatiate further on one of the 3 controls mentioned in section 4.3.1.1. considered capable of causing the initiation of channel downcutting and subsequent filling by a waning flow. This control is; the diversion of a large scale river, either suddenly or gradually, followed by cutting off of its supply. The most prominent example of this control is demonstrated during the Pule Hill period in the Rossendale area (Fig. 16), where sequences d and e show clearly the multiple major channels that characterise its delta top area. These composite channel bodies are best explained in the context of the diversion of a distributary river either suddenly or gradually followed by an up-dip cut-off of its supply as in the case of the present day Atchafalaya (Gould, 1970). Most channels of this study appear to have been abandoned slowly based on the frequent evidence of upward waning of flow strength as discussed in Chapter 4 and demonstrated by Table 19. The few instances of channels that were quickly abandoned were cited in Chapter 4. The factors most likely to have controlled the cut-off and diversion of the rivers are subsidence and variation in sedimentation rate as proposed by Moore (1958, 1960), Coleman and Gagliano (1964). However, the scale of the cut-off and the abandonment envisaged here for the multiple channel is relatively local. For the diversion of most of the rivers to have been slow suggest that a shorter and steeper alternative younger channel could have developed and taken over the discharge of the inactive original channel until it is abandoned. Admittedly, this paragraph is more of a manifestation of the long term channel behaviour, rather than on river processes factors which are being discussed, however, the basis for its discussion in the present context is the fact that such behaviour may afterall relate to the variation in sediment load (stream capacity) and transport capacity (stream competence). It also affords an opportunity to highlight the great distributary channel density that characterise the delta top area, as best illustrated by Channels 1 to 3 of Fletcher Bank Quarry (Fig. 59). Such high channel density indicates the great number of distributaries involved.

Fluvial dominance of the delta top is also indicated by the unidirectional palaeocurrents (Figs. 84-88) and supported by the absence of features generally associated with tidal channels (section 6.2.2.). The abundance of coarse distributary channels, several crevasse channels and numerous levee components in the Interdistributary Complex Association support the interpretation of a high river influence in the delta top area of this delta. Also the fact that the constructive and abandonment lithofacies are vertically distinct as discussed in section 4.3.3.4. is an evidence of the river dominance of the delta top.

Rapid progradation coupled with lateral migration of the low sinuosity distributary channels on the delta top gave rise to a delta top area that is covered by an extensive coarse channel sands, some of which are sheet-like in geometry. This widespread occurrence of the channels must be re-emphasised particularly as they appear to occur at the same stratigraphic level, as best illustrated by the Pule Hill Channels (Figs. 12, 14-17), all over the study area of some 3,000 sq.km. Rapid progradation and lateral migration of the distributary channels resulted also in the erosion of the underlying deltaic progradation sequence and most of the fine-grained Interdistributary Complex Association (Figs. 12, 14-17). As a result, coarse distributary channels may rest directly on the upper parts of the slope sediments. Several instances of this relationship were cited in section 4.2.2.2. and a model of the relationship, constructed for the Pule Hill Interval of Area 3 is shown in Figure 89. It is worth pointing out the sheet-like geometry of the mouth bar sands in this model, as such geometry implies that there must have been some significant frequent lateral shifts in the course of the rivers. It is clear from Figure 89 that even though the lowest channel erosion surfaces cut into the Slope Association, the Interdistributary Complex Association sediments were deposited at the sediment surface, prior to the erosion, which cut down into the Slope Association. In several other localities also discussed in section 4.2.2.2. it is clear that channels occasionally extended out into the slope because they distinctly occur within the mouth bar deposits and not just truncating the top. It does not appear that channels of this category migrated laterally as they occur as isolated sand bodies within the Slope Association. A conceptual model of this relationship which is constructed for the Scotland Flags Interval of Area 1 is shown in Figure 90. The sheet-like geometry of the mouth bar sediment is again emphasised by the model as in Figure 89.

6.2.2. Coastal Processes Factors

Tides and waves are regarded as coastal processes as they often redistribute and in some cases winnow the sediments deposited on the basinward edge of the advancing delta (Morgan, 1970).

Slope Association: The only noticeable coastal factor in the slope sediments is limited to the symmetrical wave ripples on the mouth-bar areas particularly in Ramsden Clough, Parkwood Quarry (Plate 10) and Bare Clough as mentioned in Chapter 4. This limited wave process is thought to have reworked the channel mouth sand and so contributed in the distribution of the sands into a sheet like geometry. Deposits of other coastal features usually characteristic of wave-influenced basins such as beaches, barriers and cheniers appear to be absent. No evidence of tidal activity was noticed in this Association.

Delta Top Assemblage: Only symmetrical ripples as discussed in Chapter 4 were recognized and it is thought that the low gradient of the delta between the distributaries might be responsible for this limited effect that the wave had on the delta (McCabe, 1975). Also no tidal effects were seen, and it may be right to conclude that the Central Pennine basin was tideless. Such a conclusion would compare with those of other workers (McCabe, 1975; Baines, 1977; Jones, 1977) who also reported a general lack of tidal effects in the E_{1c}, R_1 and R_{2b} deltas of this basin.

That coastal effects were limited is further supported by the fact that the constructive and abandonment lithofacies are vertically distinct as discussed in section 4.3.3.4. Usually in wave and/or tidally influenced deltas, basinal processes are often enhanced after delta abandonment and there is less of a contrast between progradational and abandonment lithofacies, at least in the delta front areas.

The lack of effective coastal processes implies that the Marsdenian basin had a rather low energy. The full implication of this reflects on the delta type which is further discussed in section 6.4.

6.2.3. Structural Behaviour

Because deltaic deposition takes place at the land-water boundary, tectonic or eustatic changes of basin water level necessarily influence the accumulating pile (Morgan, 1970).

The salient structural effects as tabulated by Morgan (1970) are listed below:

(i) "Stable area. Rigid basement precludes delta subsidence and forces deltaic plain to build upward as it progrades.

(ii) Subsiding area: Subsidence through structural downwarping coupled with sediment compaction allows delta to construct overlapping sedimentary lobes as it progrades.

(iii) Elevating area: Uplift of land (or lowering of sea level) causes river distributaries to cut downward and rework their sedimentary deposits".

Effect (i) above is not thought to be relevant to this discussion as the basin under consideration is not rigid. The other two effects are discussed below. Even though effect (iii) will be discussed first, effects (ii) and (iii) do not necessarily operate independently.

6.2.3.1. Relative Sea Level Changes

Although the frequent bipartite nature of each of the 3 chronostratigraphical intervals of this work namely the slope and the delta top Lithofacies Associations can be conveniently explained in terms of a simple regressive sequence, other factors suggest that some basinal level changes may have taken place. Prominent among these is the occurrence of very widespread goniatite bands (Fig. 3) thought to be indicative of an extensive transgression, related to eustatic rise of sea level following Reading (1964) and Ramsbottom (1974, 1979). Ramsbottom (1979) contends that since each of these have goniatites that characterise each of the transgressions occurs after every 250-200,000 years, and since only about 5% of the mudstones actually contain goniatites, the duration of each goniatite horizon might be of the order of 10,000-12,500 years. Some of the bands are traceable to other areas very distant from the Pennines. For instance, as mentioned in section 2.1., the _R. bilingue_ typical is traceable to North Staffordshire, North Wales and even to Belgium (Dermanet, 1941).

Naturally, any rise in sea level would be expected, through time to have a complementary fall in sea level, assuming that the sea level did not have a net rise during the Marsdenian time. That such falls occurred might be indicated by the widespread exposure of the delta top sediments commonly underlying the widespread marine bands as discussed in section 4.3.3.1. Admittedly this evidence is not conclusive as a delta top can emerge subaerially without the need for a basin level fall, that is by sedimentation on its own. A more convincing evidence of the envisaged fall is given below. The other more localized marine bands such as *R. bilingue* early and *R. metabilingue* (Fig. 3). are thought to be due to the rise being only of small amplitude, consequently making it unable to overcome the aggradation due to sediment input. Under such a condition, colonization of the delta top by vegetation was not possible. The presence of erosional channel deep within the mouth bar area as discussed in Chapter 4 and also in section 6.2.1. is probably the most convincing evidence of a fall in basin level following Read (1969), who made a similar interpretation on seeing erosional channels in a similar setting at the base of the Scottish Passage Group (Arnsbergian).

Linking the widespread distribution of individual marine bands with eustatic sea level changes in the Carboniferous of northwest Europe, Ramsbottom (1979) established more than 30 large transgressions (with intervening regressions) up to the middle part of Westphalian C. According to him each transgression was pulsed and rather slow in contrast to the rapid regression that intervened. Ramsbottom (1979) contends that in conditions of very flat topography which appear to have existed in northwest Europe during the Carboniferous, even a small change in sea level had a very large effect on the movement of the coast lines. Even though the transgressions were in general rather slow, the individual cycles of the transgressions caused big changes in coast-line position for rather small rises in sea level; he emphasised that major regressions were probably caused by only a few meters of fall in sea level. The writer however feels that sedimentation and subsidence are much more important in controlling the regressions. Such lowering of the sea level tends to shallow the basin, and by increasing the slope gave rise to the development of the major channels which cut downward leading to large influx of coarse sediment and forward building of the coast line.

How much of the prodelta sediments in each of the intervals was deposited during a falling stage of sea level and how much during any preceeding standstill is not known. Eustatic sea level rise in the study area did not only cause a major deepening of the basinal water as subsidence and compaction became dominant but also may have ponded up the incoming sediment at some point nearer the source area, consequently inhibiting aggradation and generating bays in the manner described by Scot and Fisher (1969). Such bays commonly occur between a distinct marine band and the uppermost mouth bar.

6.2.3.2. Subsidence and compaction

It is worth reiterating the fact that widespread coal on seatearth commonly occurs on the top of each of the three chronostratigraphical intervals as discussed in section 4.3.3.1. This is important because it is felt that such an occurrence signifies that during the deposition of the 40-80m thickness of strata, which is the common thickness of each of the intervals, the sedimentary surface was always close to sea level. Maintenance of such conditions for some 250-200,000 years (time gap for each of the 3 intervals according to Ramsbottom, 1979), and preservation of a considerable sedimentary record requires a fairly continuous subsidence in the depositional basin. That such significant degree of subsidence and compaction played a major role in the sedimentation is obvious even from the very nature of the three intervals. Their apparent similarity is such that they have been variously described as rhythmic (Wright et al, (1927) or cyclical (Ramsbottom 1974, 1979). Subsidence accompanied by basin level rise is commonly an important factor leading to transgression and good evidence of considerable subsidence prior to the R_2 is shown in the northern part of the basin where the basin had subsided from being a delta top environment at the end of R_{1c} to being a slope environment at the early parts of R_{2a} (see section 6.3.1.). Subsidence and compaction also characterized the sedimentation in the Central Pennine Basin prior to and during the R_1 period (McCabe, 1975). Whether the subsidence during the Marsdenian period was tectonically controlled as propounded by Bott and Johnson (1967) who contend that sedimentary loading alone cannot produce the required effect is not known. It is however felt that sedimentation rather than tectonism played the important role. Compactional control is also noticeable on local basis (Fig. 90).

6.2.3.3. Predeposition Topography

Earlier sedimentary fills appear to have influenced the pattern of sedimentation. As was discussed in section 2.2.5. and shown in Figure 28 an abnormally high water depth, probably reflective of the westward limit of growth of the Kinderscout (R_{1c}) delta system (McCabe, 1975), existed at the Rossendale area. The westward limit of growth of the Kinderscout (R_{1c}) was also proposed by Collinson et al. 1977, as the cause for the existence of a thick turbidite unit in the tunnel section located west of Blackburn which they studied in detail. This deep part of the Marsdenian basin was filled up later during the Pule Hill times by the Pule Hill delta which, like the deltas of the other 2 intervals, came from the north, particularly from the northeast as indicated by the palaeocurrent maps (Figs. 84-88). The vertical sequence in Fletcher Bank locality is similar to those of the E_1 and R_1 phases, which involves a thick turbidite and delta slope succession preceeding the establishment of shallow water delta top conditions, and contrasts with the vertical sequences of the northeast areas where the basin had been filled during the earlier R_{1c} Kinderscout fill phase.

6.2.4. Climatic factors

The high rate of sediment input demands that a considerable degree of rainfall must have taken place in the source area. The rainfall need not have fluctuated greatly, except perhaps on a seasonal basis giving floods and overbank sedimentation. Baines (1977) suggested that Britain probably experienced a seasonal monsoon-like climate and some of the vital consequences of such a setting as proposed by Schumm (1968) are as follows:

(i) In cases of total absence of grasses, barren surfaces would suffer rapid episodic erosion with marked run-off. Floods would be numerous, shortlived and intense.

(ii) Deposits of streams would resultingly be coarse-grained, and sheet-like sand units would result from sudden floods.

(iii) Infills of river channels would be flushed by major floods which would generate massive amounts of sediments moved as bed load.

Some of the evidence provided by Baines (1977) for the spread of the Carboniferous coarse arenaceous flood deposits southwards from the Caledonian mountains include the E_{1c} Skipton Moor Grit Delta and the R_1 Kinderscout Delta (Walker, 1966; Collinson, 1968, 1969; McCabe, 1975).

The factor of possible variations in fresh water supply to the Central Pennine Basin raises the debatable issue of the extent of salinity of the Central Pennine Basin. The salinity problem, as far as the Marsdenian period is concerned is discussed briefly below.

6.2.5. Salinity of the Central Pennine Basin

Most workers in the Central Pennine Basin argue that the restriction of marine fauna to thin beds of wide lateral extent must be due to the basin only rarely being fully marine. This argument is acceptable to the author only if the marine fossils are restricted consistently in their vertical distribution, in all cases. This is not always the case, because there are localities mentioned in section 4.2.2.1. where marine fossils occupy most (if not all) sections of the main body of the Scotland Flags-, Pule Hill-, and Hazel Greave Mudstones. In such cases, it is thought that the major proportion (if not entire part) of the slope concerned is marine, at least within those localities. Admittedly, the localities involved are comparatively few and geographically sporadically distributed.

Also relevant to this discussion are the marine bays occurring in between the two leaves of the Pule Hill Grit as discussed in sections 2.2.3.2. and 2.2.5. which are prominently exposed in areas 2 and 3 (30m level of b & 12m level of c, Fig. 15). In area 4, a comparable marine bay occurs again in a higher stratigraphic level as discussed in sections 2.2.3.2. and 2.2.5. The occurrence of these shallow bays at such different levels appears to verify Ramsbottom (1979) contention that each transgression in these areas "was not continuous but appears to have been pulsed, with each small transgressive pulse reaching further than its predecessor". Each of these small marine incursions may perhaps be indicating the first signs (or initial pulses) of the subsequent very widespread marine transgression, and in the particular instances mentioned above they are probably precursors of the eventual widespread transgression characterised by the band of R. bilingue late.

Hitherto, the apparent sparse evidence for the storage of coarse sands at the mouth bar areas of some parts of the Central Pennine Basin has been explained in the context of low basin salinity (McCabe, 1975). The ample evidence of the storage of coarse sand in the mouth bar areas of most localities of this study probably argues against the need for the basinal water to be low in salinity during periods of active sand supply. However, faced with these instances of normal basin salinity during the Marsdenian period, albeit sporadic, one is tempted to ask whether adequate sample data size has been collected to justify any confident generalization either way. In any case, based on the evidence of the present work, the writer feels that while the Marsdenian basin of the Central Pennineswas dominantly marine in a few localities, in most other localities it was undisputably marine at times, but the apparent barren nature of the rest of the sequence does not necessarily mean that it was not marine. Whatever the salinity state of the entire basin, it is felt that the variation in fresh water supply to the basin could generate basinal salinity changes on small scale basis and certainly not on the same scale as the eustatic changes in sea level, particularly those characterised by the R. gracile, R. bilingue typical, R. bilingue late and R. superbilingue goniatites.

6.2.6. Synthesis of the Factors Controlling Sedimentation

The major factors controlling sedimentation discussed in the above section 6.2.1. to 6.2.5. are summarised as follows:

(i) River Processes Factors: Effects of the High River processes that generated are noticeable right from the Deep Water Association through the Slope Association to the Delta Top Areas.

(ii) Coastal Processes: There is no evidence for tidal activity and the effects of wave processes are limited to symmetrical ripples in the mouth bars and delta top areas.

(iii) Structural Behaviour: (a) Subsidence accompanied by relative basin level rise led to transgression (b) High rate of sedimentation and subsidence-compaction played a major role in generating regressions (c) Regressions gave rise to the development of the distributary channels which cut downwards leading to large influx of coarse sediment and forward building of the coastline (d) Westward limit of growth of the Kinderscoutian (R_{1c}) delta controlled the pattern of sedimentation.

(iv) Climatic factors: High degree of rainfall led to high rate of sediment input.

(v) Salinity of the Basin: The basin was probably fully marine in some few localities. However, in most other localities, it was marine at times but is is not clear yet whether the rest of the basin was marine or not.

6.3. Palaeogeography

6.3.1. Introduction. Early Namurian Sedimentation

At the start of the Namurian, a deep basin existed in northern England. The northern edge of the basin was bounded by the Craven Fault forming the boundary of the Askrigg Block. The southern boundary lay along the northern edge of the Midland landmass. The eastern and western limits are not clear, however, in the east it appears probable that several 'gulfs' and 'ridges' extended westwards from a basin margin, whereas to the west there is a likelihood that the basin continued into, or at least connected with basins in Ireland. At the commencement of detrital infilling of this basin, it is probable that water depths in the deeper parts of the basin were of the order of several hundreds of meters, while higher the topographical blocks lay under shallower water.

This basin (that is, Central Pennine Basin) experienced the following 3 major phases of fill during the Namurian, each fill representing the advance of a different type of delta into the basin. (The listing below is in accordance with the period of the influx):

(i) E_{1c} Zone: Involves the Pendle and Skipton Moor Grit (Reading, 1964; Baines, 1977).

(ii) R_1 Zone: Involves the Kinderscout Grit Group (Reading, 1964; Collinson 1967, 1969; McCabe, 1975). During this interval, R_{1c} marks the major period of delta advance, and by the end of R_{1c} delta top condition were established in all the Central Pennine areas excepting the westernmost parts (McCabe, 1975), that is, the Samlesbury (SD 620290) areas. However, at the end of the Kinderscoutian period, a final transgression, marked by the R. gracile band submerged the entire R_{1c} delta top.

(iii) R_2 Zone: Involves the Marsdenian sediments of this study, as discussed below, but also the Alum Crag Grit in Lancashire (Collinson et al., 1977) and the Roaches Grit Group (Jones, 1977).

Figures 12, 14-17 give a picture of the lateral and vertical relationship of the lithofacies associations discussed in Chapter 4 and this picture is relevant to the discussion of the reconstructed history of the sedimentation and the palaeogeography of the Central Pennine Basin during the deposition of the Marsdenian sediments of this study as discussed below.

6.3.2. Marsdenian Sedimentation

6.3.2.1. Scotland Flags Interval

The first post-R. gracile fluviatile conditions were established in the north eastern parts of area 3 as is suggested by the presence of coarse-grained and pebbly R_{2a} channel units in Derry Hill Quarry (k, SE 166435) and Riddlesden Quarry (l, SE 068430, Plates 72A & 72B). The presence of other distinct R_{2a} channel sand bodies at Castle Carr Quarry (m, SE 028301), Head Luddenden (n, SE 021308), Bare Clough (o, SE 019309), Riverside Cemetary Quarry, Sowerby Bridge (p, SE 053237; associated with major slumping). Triangle Railway Cutting (q SE 047224), Hey Lane Clough (r SE 062172) and at Red Lane Dike (s, SE 066175) all in area 2 and also at Diggley Quarry (t, SE 110074) in area 1, makes the author believe that the position of the shoreline at the end of the R_{2a} period (that is immediately pre R. bilingue typical) may be as shown in Figure 85. For the shoreline to be in this proposed position, it is likely that the channel that deposited the sediments in Diggley Quarry may be different from the one responsible for the deposits in Riverside Cemetary Quarry, Triangle Railway and other northern localities based on palaeocurrent evidence (Fig. 85), sand body geometry and lithology as discussed in Chapters 3 and 4 and also the geographical location of the Diggley Quarry.

Also at the end of the R_{2a} period, while the XX and YY channels were depositing their coarse sands in Bradford, Halifax and Huddersfield areas (northeast and eastern areas), the earliest R_{2a} slope deposits, some of which contain Prodelta turbidites, were spreading from Keighley areas (SE 066407) in the northeast through Hebden Bridge areas in the centre to the Holme Moss areas in the south, and as far west as Sabden Brook (SD 7466341). Extensive mouth bar deposits characterise the upper slope sedimentation. Because of the lack of the exposure of R_{2a} sediments around Burnley, Todmorden and Rochdale areas it is difficult to demarcate the westward limit of the mouth bar sediments with any confidence. However, based on the occurrence of the Deep Water Marine Sediments in Fletcher Bank Section (M9) and the Prodelta sediments in Sabden Brook (M10) it is likely that this boundary will be in the areas of Todmorden-Rochdale as suggested in Figure 85. This interpretation is also in agreement with the isopach map evidence (Fig. 27) which indicates a change in pre-R_{2a} topography commencing just to the southwest of Rochdale. Collinson et al. (1977) suggested from their facies analysis of a tunnel section located some 8km west of the westernmost part of this study area that their delta slope did not extend any further westwards of Blackburn in the period between R. gracile and R. bilingue. The present study verifies this contention. The following important facts are worth noting.

(i) Most of the palaeocurrents measured through the inferred slope sediment trend towards the southwestern direction of the delta advance (Figs. 84-87) suggesting downslope underflow. Whether this underflow is related to reduced basin water salinity (Collinson et al, 1977) is not clear.

(ii) At this same end of R_{2a} time that channel sediments and other delta top facies are being deposited at the northeastern and eastern parts of the study area, and slope sediments deposited between Sabden areas in the west to Keighley-Hebden Bridge-Holme Moss areas to the east, the first Marsdenian deep water turbidites deposited west of Blackburn

(Collinson *et al.* 1977).

At the end of the R2a period, a very widespread transgression thought to be associated with eustatic sea level rise and characterised by the band of the *R. bilingue* typical goniatite submerged the entire R_{2a} delta lobe.

In summary, delta top conditions were restricted to the northeast and eastern parts of the study area during the R_{2a} period when slope sediments occupied the rest of the central, southern and western parts, and the deep water turbidites were depositing some 8 km west of the study area. A widespread transgression terminated the delta influx and marks the end of the R_{2a} period.

6.3.2.2. Pule Hill Interval

Following the transgression that terminated the R2a delta, the Central Pennine basin was again infilled by another deltaic advance, the R2b (or Pule Hill) delta. The R2b period is marked by the most prominent southwestward Marsdenian delta progradation, the thickness pattern of which appears to be largely controlled by the earlier sedimentary fill.

The Scotland Flags deposits are too thin to have influenced the Pule Hill sedimentation or even to expose what effects earlier palaeotopography might have had on them, as they probably merely mantled their predepositional palaeotopography. The most prominent palaeotopographical influence is seen in Fletcher Bank (Figs. 27 & 28) as discussed in section 2.2. It is necessary to reiterate that it is only in this thickest part of the Pule Hill basin that the deep water turbidites (cf. Blackburn, Collinson *et al.*, 1977) of the Pule Hill zone were deposited. If the base of the bay sediment (255m, e, Fig. 16) which directly overlies the mouth bar deposits of the Fletcher Bank, deposited close to the top level of the basin, based on its shallow water characteristics (Okolo, 1982, in press), then the lowest R_{2b} turbidites in Fletcher Bank must have deposited at some 230m (e, Fig. 16) water depth. In fact, if the lowest observed coal, which is on top of Channel 3 (283m, e, Fig.16) is taken as the reference datum then the lowest turbidite-like sandstone will be some 260m deep. This can even be increased somewhat by the application of a compaction factor, following McCabe (1975) who approximately calculated the overall percentage compaction of the Kinderscout sediments to be 25%. Since the Kinderscout sediments do not differ significantly in lithology from the Marsdenian sediments, applying this compaction factor will give a depth of some 325m for the Pule Hill deepest basin during the deposition of the turbidites. This unusually high depth is thought to reflect the original basin depth which may be related to the westward limit of the Kinderscout delta (McCabe, 1975). By comparison however, deep water turbidites also occur near Macclesfield (Evan et al. 1968), and in the south west Pennines (Jones, 1977) during the R_{2b} period.

The slope sedimentation which appears to be restricted to the early periods of R_{2b} appear similar to the R_{2a} slope sediments both in their Prodelta turbidite content and in good mouth bar development. This period is also characterised by a remarkable activity of burrowing organisms(Fig. 101), particularly in the mouth bar areas. Crawling activity of organisms particularly Olivellites was great. Other trace fossils occurring in the mouth bar areas at this time include Gryrophyllites, 'Scolicia', Cochlichnus, Planolites, Korphichnium rossendalensis, ?Phycodes palmatum, Pelecypodichnus and Palaeophycus. The diversity of these trace fossils are thought to be controlled by the mode of deposition of their host sediments. It is also possible that their great increase is because of less exacting environment, as neither desiccation nor large and sudden fluctuations in temperature nor even fast-flowing wave and tidal currents are envisaged. Olivellites, which appears most prominent in this mouth bar environment, possible possessing stratigraphic significance, reaches its climax during this period. What is most significant about this period however, is that towards its end (that is immediately pre- R. bilingue late band), delta top conditions were established in all the areas of the basin (Fig. 86), except in a few sporadically distributed localities such as Wessenden Reservoir (SE 062087), Ramsden Clough (SE 121038) in area 1, Colne Road Mill Borehole (SE 145159) and Bowers Mill Borehole (SE 070203) in area 2. The distributary channels whose sediments are dominantly coarse-to very coarse-grained occasionally pebbly are very widespread and occur all over the study area. Based on the occurrence of coarse-grained distributary channels in Sabden Brook and Fletcher Bank areas, localities that contained prodelta and deep water marine sediments respectively during the R_{2a} period and in conjunction with palaeocurrent evidence, it is felt that the coastline had advanced west of the study area, and in fact may have advanced some 10km west of the westernmost limit of the study based on the evidence of Collinson et al. (1977) work. The great diversity in trace fossil activity in the mouth bar area appears to be carried over into the delta top assemblage and particularly within the Interdistributary Complex Association. Ichnogenera Arthrophycus, Palaeophycus, Phycodes curvipalmatum, Arenicolites, and Pelecypodichnus characterise the delta top and their distribution appears to be controlled by the mode of deposition of their host sediments. Coal on seatearth occurring on most of the Distributary Channels (Fig. 12, 14-17) marks the establishment of terrestrial condition towards the end of the Pule Hill Interval and signifies its abandonment prior to a widespread transgression probably related to eustatic sea level rise and characterised by R. bilingue late band which again submerged the entire Pule Hill delta.

6.3.2.3. Hazel Greave Interval

The water depth after the R. bilingue late transgression is shallowest in most area, compared with those associated with the R. gracile and R. bilingue typical goniatites. Consequently, bays and prodeltas are juxtaposed in several areas (Figs.12, 14-17). These shallow waters were gradually infilled by deltaic sequences whose clastic and ichnologic contents resemble those of Pule Hill Interval. In none of these localities were the Prodelta Turbidites noticed as in Scotland Flags Interval and Pule Hill Interval. However, non-turbiditic density current deposits associated with slumping were recognized in the Hazel Greave Interval section in Longworth Valley Exposure (a, Fig.16). Fluviatile sedimentation, some of which was associated with synsedimentary faulting and slumping was remarkable during this period. Data on the Hazel Greave sediments are comparatively limited, however, on the basis of the exposed parts plotted in Figure 87, it appears that the distribution of the delta top components at the end of the Hazel Greave Interval is similar to the distribution at the end of the Pule Hill Interval. Good channel-fill sediments were recognized right from the north-eastern parts, particularly around Guiseley areas, to as far west as Harper Clough Quarry just south of Blackburn. Again towards the end of Hazel Greave Interval, terrestrial conditions were estimated in most parts of the basin and the widespread occurrence of coal on seatearths is also evidence of abandonment of the delta and the emergent to near emergent conditions throughout the basinal area. At the end of the Hazel Greave interval a final widespread transgression probably triggered by eustatic sea level rise and characterised by the band of the R. superbilingue goniatite submerged the entire delta top of the study area.

6.4. The Marsdenian Delta Type and Morphology

The sheet-like geometry of the mouth bar sands discussed in section 6.2.1. (Figs. 28, 89 and 90) the extensive distribution and sometimes sheet-like geometry of the distributary channel sand-bodies (Figs. 12, 14-17 & 89), the truncation of the upper parts of the mouth bar sands by distributary channels (Fig. 89) and the limited influence of the coastal processes within the mouth bar areas are explicable in the following context:

(i) River activity must have been substantial within this delta.

(ii) Substantial lateral shifts of these channels must have taken place consequently causing the coalescence of mouth bar sands.

(iii) There might have been some wave reworking of these channel mouth bar sands. Such reworking might have contributed also in the distribution of the mouth bar sands to form sheet-like sand-bodies.

Based on these features and bearing in mind that the level of coastal processes is relevant in deciding the ultimate shape of a delta (Fisher et al. 1969; Colemand and Wright, 1975) the Marsdenian delta of this study would be classified as a High Constructive delta using the terminology of Fisher et al. (1959). The limited wave modification may have contributed in making the Scotland Flags Delta lobate shaped in plan view (Fig. 85). On a discussion of the delta types that infilled the Central Pennine Basin during the Namurian, Collinson (1976), suggested the following 3 delta types each listed with its diagnostic sedimentological features.

A. Deep-Water Turbidite Fronted Deltas

(i) Several hundreds of metres thick (up to 300m deep).

(ii) Consists of a lower turbidite unit, a middle dominantly silty upwards coarsening delta slope, and an upper delta top part dominated by mutually erosive channels filled with coarse sandstones.

(iii) Upper slope portrays evidence of slump scars.

B. Shallow-Water Sheet Deltas

(i) The whole sequence is usually less than 100m thick.

(ii) Turbidite deposits are generally absent.

(iii) Consists of coarsening-up mudstone-siltstone slope deposit.

(iv) Topped by a sheet sandstone attributed to migrating distributaries.

C. Shallow Water Elongate Deltas

(i) Like B, displays a coarsening-up sequence too.

(ii) Topped by a current parallel elongate sand body.

(iii) Its complex internal geometry is relatable to modern bar-finger sands and presumed mouth bars.

It is felt that the Marsdenian Deltas envisaged here belongs broadly to type B above, based especially on the similarities existing between them in terms of thickness of sequence, vertical sequence organization and delta top types. However, there are important differences between the Marsdenian Deltas of this work and the Shallow Water Sheet Deltas as envisaged above. For instance, the Deep Water Sediment of Fletcher Bank compares more with type A delta above than with type B. The presence of the Prodelta turbidites were not recognized in descriptions of type B deltas whereas they are important integral part of the Marsdenian deltas, especially during the R_{2a} and R_{2b} periods. Based on these important differences, particularly the Prodelta turbidites factor, it is suggested that the description of Shallow Water Sheet Deltas of the Central Pennine Basin be expanded to accommodate these Prodelta turbidites.

Investigations of the Mississippi delta have helped to elucidate the vital differences between lobate and elongate (birdfoot) river-dominated deltas, primarily based on the basis of sand distribution patterns (Fisk 1955, 1961, Fisk et al. 1954). In lobate deltas for instance numerous distribution channels with closely spaced mouth bar sands produce a sheet-like distribution of sand. This distribution pattern applies to the delta under discussion and the high density of the distributary channels involved has been discussed in section 6.2.1. Elongate deltas have fewer distributaries and the sand lithofacies are confined to narrow bar-fingers of distributary channel and mouth bar sediments, separated by thick wedges of pro-delta and interdistriburaty bay silts and muds. This relationship does not apply to the delta envisaged here.

The best known present day analogue to the delta model proposed here is the Lafourche delta of the Holocene Mississippi (Fisher et al., 1969; Fig. 91) which are large scale features whose constituent facies are the dominantly thick constructional facies that are vertically distinct. Other relevant features of this lobate High Constructive Delta of Fisher (1969) which make it a good analogue of the Marsdenian Deltas of this study include the following.

(i) An extensive delta top facies made up principally of thick distributary channel sands and a variety of interdistributary or non channel deposits consisting mostly of muds, thin muddy sands and abundant in situ accumulation of coal.

(ii) A down dip delta front facies consisting chiefly of sands forming a lobate fringe to the delta plain facies.

(iii) A basinward prodelta facies, the thickest of the delta facies and made up of mainly dark organic-rich laminated muds.

As discussed in section 6.3.2.2. the extensive nature of the delta areas of the Marsdenian Delta is best demonstrated by the Pule Hill and the Hazel Greave Deltas whose delta top areas cover the entire study area (some 3,000 sq km). The Fletcher Bank Quarry, provides the best single locality for the study of typical delta top setting of the Pule Hill delta, for reasons discussed in Chapter 4. The various elements of the Prodelta-Mouth Bar, Distributary, Interdistributary and Abandonment Associations were discussed in detail in Chapter 4, and they bear remarkable resemblance to these three significant features of the Lobate High Constructive Deltas listed above. It is worth re-emphasising the fact that deposition of sand in both the Marsdenian deltas of this work and their Holocene Mississippi analogue took place both in the mouth-bar region and within the major channels in contrast to the pattern at the Roaches Grit Group of the Central Pennine. In the latter, most deposition took place only within the deep channels. The Roaches Grit however resemble the Scotland Flags-, Pule Hill-, and Hazel Greave deltas in the behaviour of their channels, which compare with those of modern sandy low sinuosity rivers. Frequent lateral shifts in the course of the rivers resulted in the construction of sheet sandstones.

The erosive bases of some of the slope sandstones and the unidirectional nature of palaeocurrents are indicative of the fact that strong currents operated on the slope and may well have been the occasional hyperpycnal flows (that is, turbidity currents) that occasionally issued from the distributaries and the mouth bar areas, during times of flood. Non-turbidity density current underflows of the type postulated by McCabe (1975) and Jones (1977) also operated in other parts of the delta.

REFERENCES

Ager, D.V. & Wallace, P. (1970). The distribution and significance of trace fossils in the uppermost Jurassic rocks of the Boulonnais, northern France. In: Trace fossil (Ed. by T.P. Crimes & J.C. Harper). Geol. Jour., Spec. issue, 3, 1-18. text Fig. 1-7. pl.1, Seel House Press (Liverpool).

Allen, J.R.L. (1960). The Mam Tor Sandstones: a turbidite facies of the Namurian deltas of Derbyshire, England. J. sedim. Petrol. 30, 193-208.

-------------- (1963). The classification of cross-stratified units, with notes on their origin. Sedimentology, 2, 93-114.

-------------- (1964). Primary current lineation in the Lower Old Red Sandstone, Anglo-Welsh Basin. Sedimentology, 3, 89-108.

-------------- (1965a). Late Quaternary Niger delta and adjacent areas: Sedimentary environments and lithofacies. Bull. Am. Ass. Petrol. Geol. 49, 547-600.

-------------- (1965b). A review of the origin and characteristics of Recent alluvial sediments. Sedimentology, 5, 89-191.

-------------- (1966). On bedforms and palaeocurrents. Sedimentology, 6, 153-190.

-------------- (1968). "Current Ripples", p.433. North-Holland, Amsterdam.

-------------- (1970). "Physical Processes of Sedimentology". pp.248. Unwin, London.

American Commission on Stratigraphic Nomenclature. (1961). Code of Stratigraphic Nomenclature. Bull. Am. Ass. Petrol. Geol. 45, No. 5, 645-665.

Ashton, C.A. (1970). Palaeontology, stratigraphy and sedimentology of the Kinderscoutian and Lower Marsdenian (Namurian) of North Staffordshire and adjacent area. Unpublished Ph.D. Thesis, University of Keele.

Baines, J.G. (1977). The Stratigraphy and Sedimentology of the Skipton Moor Grits (Namurian E_{1c}) and their lateral equivalents. Unpublished Ph.D. thesis, University of Keele.

Barrel, J. (1914). The Upper Devonian delta of the Appalachian geosyncline. Am. J. Sci., 37, 225-253.

Bates, C.C. (1953). Rational theory of delta formation. Bull. Am. Ass. Petrol. Geol., 37, 2119-2162.

Benfield, A.C. (1969). The Huddersfield White Rock cyclotherm in the Central Pennines, Report of field meeting. Proc. Yorks. Geol. Soc., 37, 181.

Bernard, H.A. & Leblanc, R.J. (1965). Resume of Quaternary geology of the northwestern Gulf of Mexico province. In: The Quaternary of the United States: Princeton, N.J., Princeton Univ. Press, 137-185.

Binney, E.W. (1839). The Lancashire and Cheshire Coalfield. Trans. Geol. Soc., Manchester, 1, p.78.

---------------- (1852). On some trails and holes found in rocks of the Carboniferous strata, with remarks on the Microconchus carbonarius: Manchester Lit. Philos. Soc., Mem. & Proc., ser. 2, 10, 181-201.

Bisat, W.S. (1924). The Carboniferous goniatites of the north of England and their zones. Proc. Yorks. geol. Soc. 20, 40-124.

---------------- (1928). The Carboniferous goniatites zones of England and their continental equivalents. Congr. de. Strat. Carb., Heer len. p.117.

Black, R.M. (1970). "The Elements of Palaeontology". 339p. Jarrold & Sons, London.

Bluck, B.J. & Kelling, G. (1963). Channels from the upper carboniferous coal measures of South Wales. Sedimentology, 2, 29-53.

Bott, M.H.P., and G.A.L. Johnson (1967). The controlling mechanism of Carboniferous cyclic sedimentation. Q. Jl. geol. Soc. Lond. 122, 421-41.

Bouma, A.H. (1962). "Sedimentology of some flysch deposits; a graphic approach to facies interpretation", 168pp. Elsevier, Amsterdam.

Bromehead, C.E.N., Edwards, W., Wray, D.A., and Stephens, J.V. (1933). The Geology of the country around Holmfirth and Glossop. Mem. Geol. Surv., H.M.S.O.

Busch, D.A. (1971). Genetic Units in Delta Prospecting. Bull. Am. Ass. Petrol. Geol. 55, No. 8, 566-580.

---------------- (1974). "Stratigraphic Traps in Sandstones-Exploration Techniques". 174p. Am. Ass. Petrol. Geol. Tulsa. Oklahoma.

Campbell, C.V. (1967). Lamina, laminaset, bed and bedset. Sedimentology, 8, 7-26.

---------------- (1976). Reśervoir geometry of a fluvial sheet sandstone. Bull. Am. Ass. Petrol. Geol. 60, 1009-1020.

Casey, J.M. (1980). Depositional Systems and Basin evolution of the late Palaeozoic Taos Trough, northern New Mexico. Ph.D. Dissertation, University of Texas, Austin, Rep. No. UT80-1, 236p.

Chamberlain, C.K. (1971). Morphology and ethology of trace fossils from the Quachita Mountains, south-eastern Oklahoma. Jour. Palaeo., 45, 212-246.

Coleman, J.M. (1969). Brahmaputra River: Channel processes and sedimentation. Sedim. Geol., 3, 129-239.

---------------- (1976). Deltas: processes of deposition and models for exploration: Continuing Education Pub. Co., Inc., 102p.

Coleman, J.M. & Gagliano, S.M. (1964). Cyclic sedimentation in the Mississippi river delta plain. Trans. Gulf-Cst. Ass. geol. Socs., 14, 67-80.

------------ & Gagliano, S.M. (1965). Sedimentary structures: Mississippi River deltaic plain. In: Primary Sedimentary Structures and their Hydrodynamic Interpretation (Ed. G.V. Middleton). Spec. Publ. Soc. Econ. Palaeont. Miner., Tulsa, 12, 133-148.

-------------- Gagliano, S.M. & Webb, J.E. (1964). Minor Sedimentary structures in a prograding distributary. Mar. Geol. 1, 240-258.

-------------- Suhayda, J.N., Whelan, T. & Wright, LD. (1974). Mass movement of Mississippi river delta sediments. Trans. Gulf-Cst. Ass. geol. Socs., 24, 49-68.

-------------- & Wright, L.D. (1975). Modern river deltas: variability of processes and sand bodies. In: Deltas, Models for Exploration (Ed. M.L. Broussard). 99-149pp. Houston Geol. Soc. Houston.

Collinson, J.D. (1966). Antidune bedding in the Namurian of Derbyshire. Geologie Mijnb. 45, 262-4.

-------------- (1967). Sedimentation of the southern part of the Grindslow Shales and the Kinderscout Grit. Unpublished Ph.D. thesis, University of Oxford.

-------------- (1968). Deltaic Sedimentation units in the upper Carboniferous of northern England. Sedimentology, 10, 233-54.

-------------- (1969). The sedimentology of the Grindslow Shales and the Kinderscout Grit: a deltaic complex in the Namurian of northern England. J. Sedim. Petrol. 39, 194-221.

--------------- (1970a). Deep channels, massive beds and turbidity current genesis in the Central Pennine Basin. Proc. Yorks. geol. Soc. 37, 495-520.

Collinson, J.D. (1970b). Bedforms of the Tana River, Norway. Geogr. Annlr. 52, 31-56.

--------------- (1976). Deltaic Evolution during Basin Fill- Namurian of Central Pennine Basin, England. (Abstract). Bull. Am. Ass. Petrol. Geol. 60, 659.

--------------- (1978a). Alluvial Sediments. In: "Sedimentary Environments and Facies". (Ed. by H.G. Reading), pp.15-60. Blackwell Scientific Publications, Oxford.

---------------- (1978b). Vertical sequence and sand body shape in alluvial sequences. In: Fluvial Sedimentology (Ed. by A.D. Miall). Mem. Can. Soc. petrol. Geol. Calgary, 5, 577-586.

---------------- & Banks, N.L. (1975). The Haslingden Flags (Namurian G_1) of south-east Lancashire: bar finger sands in the Pennine Basin. Proc. Yorks. geol. Soc. 40, 431-458.

---------------- Jones, C.M. & Wilson, A.A. (1977). The Marsdenian (Namurian R_2) succession west of Blackburn; implications for the evolution of Pennine delta systems. Lpool Manchester Geol. J. 12, 59-76.

Conaghan, P.J. & Jones, J.G. (1975). The Hawkesbury Sandstone and the Brahmaputra: A depositional model for continental sheet sandstones. Jl. Geol. Soc. Australia. 22, pt.3, 275-283.

Crimes, T.P. (1975). The stratigraphical significance of Trace Fossils. In: "The Study of Trace Fossils; A synthesis of Principles, Problems and Procedures in Ichnology". (Ed. by R.W. Frey), pp.109-130. Springer-Verlag Berlin Heidelberg New York.

---------------- (1970). The significance of trace fossils in sedimentology, stratigraphy and palaeoecology with examples from lower palaeozoic strata. In: "Trace fossils". (Ed. by T.P. Crimes & J.C. Harper), Geol. Jour., Spec. Issue No.3, 101-126, Seel House Press. Liverpool.

Dakyns, J.R., Fox-Strangways, C., Russel, R. & Dalton, W.H. (1879). The Geology of the county between Bradford and Skipton. Mem. Geol. Surv.

Davis, J.W. & Lee, F.A. (1880). West Yorkshire. 2nd edition. 8vo, London.

Deans, T. (1934). A second boring in the Millstone Grits of Rombalds Moor. Trans. Leeds geol. Assoc. 5: 75-85

Demanet, F. (1941). Fauna et stratigraphie de l'etage Namurian de la Belgique. Memoires du Musee Royal D'Histoire Naturelle de Belgique, Memoire no. 97. 1-327pp.

Eager, R.M.C. (1974). Shape of shell of Carbonicola in relationship to burrowing. Lethaia, 7, 219-238.

---------------- (1977). Some new Namurian bivalve faunas and their significance in the origin of Carbonicola and in the colonization of carboniferous deltaic environments. Phil. Trans. roy. Soc. (B). 280, 535-70.

---------------- Okolo, S.A. & Walters, G.P. (in press). Trace fossils as evidence in the evolution of Carbonicola.

---------------- Baines, J.G., Collinson, J.D., Hardy, P.G., Okolo, S.A. & Pollard, J.E. (in press). Trace fossil assemblages and their occurrence in Silesian (mid-Carboniferous) deltaic sediments of the Central Pennine Basin, England. In: "Biogenic Structures: their use in interpreting depositional environments". (Ed. by H.A. Curren). S.E.P.M.

Earp, J.R., Magraw, D., Poole, E.G., Land, D.H., Whitman, A.J. (1961). Geology of the country around Clitheroe and Nelson. Mem. Geol. Surv. Gt. Britain, H.M.S.O., London. 244pp.

Edwards, W., G.H. Mitchell and T.H. Whitehead (1950). Geology of the District North and East of Leeds. Mem. Geol. Surv. H.M.S.O.

Elliott, T. (1974a). Abandonment facies of high-constructive lobate deltas, with an example from the Yoredale Series. Proc. Geol. Ass., 85, 359-365.

-------------- (1974b). Interdistributary bay sequences and their genesis. Sedimentology, 21, 611-622.

-------------- (1976a). Upper Carboniferous sedimentary cycles produced by river-dominated, elongate deltas. J. Geol. Soc., 132, 199-208.

-------------- (1976b). The morphology, magnitude and regime of a Carboniferous fluvial-distributary channel. J. sedim. Petrol., 46, 70-76.

-------------- (1978). Deltas. In: "Sedimentary Environments and Facies". (Ed. by H.G. Reading), pp. 9-142. Blackwell Scientific Publications, Oxford.

Evans, W.R., Wilson, A.A., Taylor, B.J. & Price, D. (1968). Geology of the country around Macclesfield, Congleton, Crewe & Middlewich. Mem. Geol. Surv. U.K. 328 pp.

Fenton, C.L., & Fenton, M.A. (1937). Olivellites, a Pennsylvanian snail burrow. Am. Midland Naturalist. 18, No. 3, 452-453.

Fisher, W.L. (1969). Facies characteristics of the Gulf Coast Basin delta systems, with some Holocene analogues. Trans. Gulf. Cst. Ass. geol. Socs. 19, 239-61.

-------------- & Brown, L.F. (1969). Delta systems and oil and gas occurrence. In: Delta Systems in the Exploration for Oil and Gas (Ed. by Fisher, W.L., Brown, L.F., Scott, A.J., & McGowen, J.H.), pp. 54-78. Bur. econ. Geol., Univ. Texas, Austin.

Fisk, H.N. (1947). Fine Grained Alluvial Deposits and their Effects on Mississippi River Activity. pp.82. Mississippi River Commission, Vicksburg, Miss.

Fisk, H.N. (1955). Sand Facies of recent Mississippi delta deposits. Wld. Petrol. Cong., Rome, 377-398.

------------- (1961). Bar finger sands of the Mississippi delta. In: Geometry of Sandstone Bodies - a symposium (Ed. J.A. Peterson & J.C. Osmond), pp. 29-52. Am. Ass. Petrol. Geol., Tulsa.

-------------- McFarlan, E. Jr., Kolb, C.R. & Wilbert, L.J. Jr. (1954). Sedimentary framework of the modern Mississippi delta. J. sedim. Petrol., 24, 76-99.

Flores, R.M. (1972), Delta Front-Delta Plain Facies of the Pennsylvanian Haymond Formation. Northeastern Marathon Basin, Texas. Geol. Soc. Am. Bull., 83, 3515-3424.

-------------- (1974). Characteristics of the Pennsylvanian Lower-Middle Haymond Delta-Front Sandstones, Marathon Basin, West Texas, Geol. Soc. Am. Bull., 85, 709-716.

-------------- (1981a). Coal deposition in Fluvial Palaeoenvironments of the Paleocene Tongue River Member of the Fort Union Formation, Powder River Area, Powder River Basin, Wyoming & Montana. In: Recent and ancient nonmarine depositional environments: models for exploration (Ed. by R.M. Flores). Spec. Publ. Soc. econ. Paleont. Miner., Tulsa. No.31, 169-190.

--------------- & Erpenbeck, M.F. (1981). Differentiation of Delta-front and barrier lithofacies of the upper Cretaceous pictured cliffs sandstone, southwest San Juan Basin, New Mexico. The Mountain Geol. 18, No. 2, 23-34.

Fürsich, F.T. (1974a). Ichnogenus Rhizocorallium. Palaeont. Zeitschr. 48, 12-28.

-------------- (1974b). Corallian (Upper Jurassic) trace fossils from England & Normandy. Stuttgarter Beiträger zur naturkunde, Ser. B, No. 13, 1-52.

Gagliano, S.M. & W.G. McIntire. (1968). Reports on the Mekong River Delta. Reprinted in: Deltas: Recent & Ancient (Ed. by R.S. Saxena, J.C. Ferm and J.M. Coleman) 1-7, New Orleans Geol. Soc. Continuing education seminar, Nov. 28-30, 1972, 169pp.

Gilligan, A. (1920). The petrology of the Millstone Grit of Yorkshire. Q. Jl. geol. Soc. London. 75, 251-94.

Glocker, F.E. (1841). Über die Kalkführende Sandstein formation auf beiden Seiten der Mittleren March, in der Gegend Zwischen kwassitz und kremsier; Nova Acta Acad Caes. Leop.-Carol. German Natur. Curios., v.19, suppl.2, p.309-334.

Goddard, E.N. (Chairman) (1971). Rocks-colour Chart. Rock Colour Chart Committee New York Geol. Soc. America.

Gould, H.R. (1970). The Mississippi Delta Complex. In: Deltaic sedimentation Modern and Ancient (Ed. by J.P. Morgan). Spec. Publ. Soc. econ. Paleont. Miner., Tulsa, 15, 3-30.

Green, A.H. (1878). Geology of the Yorkshire Coalfield. Mem. Geol. Surv.

-------------- Dakyns, J.R., Ward, J.C. & Russell, R. (1871). The geology of the neighbourhood of Dewsbury, Huddersfield and Halifax. Geological Survey Mem. 8, pp.10, London.

-------------- Russell, R., Dakyns, J.R., Ward, J.C., Fox-Strangways, C., Dalton, W.H. & Holmes, T.V. (1878). Geology of the Yorkshire Coalfield. Mems. Geol. Surv. 8. London.

Hakes, W.G. (1976). Trace Fossils and depositional environments of four clastic units, Upper Pennsylvanian mega cyclothems, north-east Kansas. In: The University of Kansas Palaeo. Contrib., Article 63, 1-46.

Hall, J. (1847). Palaeontology of New York. 1, (Albany).

--------- (1852). Palaeontology of New York. 2. (Albany).

Hallam, A. (1970). Gyrochorte and other trace fossils in the Foreset Marble (Bathonian) of Dorset, England. In: Trace Fossils (Ed. by T.P. Crimes & J.C. Harper). Geol. Jour., Spec. issue No.3, 189-200, Seel House Press (Liverpool).

-------------- (1975). Preservation of trace fossils. In: "The study of trace fossils: A synthesis of Principles, Problems and Procedure in Ichnology". (Ed. by R.W. Frey), pp.55-64. Springer-Verlag Berlin Heidelberg New York.

Häntzschel, W. (1975). Trace fossils and problematica: In: Treatise on invertebrate palaeontology. (Ed. by Curt Teichert). Part W, Supplement 1, Geol. Soc. America and Univ. Kansas (Boulder, Colo., Lawrence, Kansas).

Hardy, P.G. (1970a). Xiphasurid trails from the Upper Carboniferous of northern England. Palaeontology, 13, 188-190.

--------------- (1970b). Aspects of palaeoecology in the arenaceous sediments of Upper Carboniferous age in the area around Manchester. Unpublished Ph.D. Thesis, University of Manchester.

Harms, J.C. and R.K. Fahnestock (1965). Stratification, bedform and flow phenomena (with an example from the Rio Grande). In: "Primary Sedimentary Structures and their Hydrodynamic Interpretation" (Ed. by G.V. Middleton). Spec. Publ. Soc. Econ. Palaeont. Miner., Tulsa, 12, 84-115.

-------------- Southard, J.B., Spearing, D.R. & Walker, R.G. (1975). Depositional environments as interpreted from primary sedimentary structures and stratification sequences. Soc. Econ. Pal. and Miner. Short Course N.2, pp. 161. Dallas, Texas.

Heckel, P.H. (1972). Recognition of ancient shallow marine environments. In: Recognition of ancient sedimentary environments. (Ed. by J.K. Rigby and W.M.K. Hamblin). Spec. Publ. Soc. Econ. Palaeont. Miner., 16, 226-286.

Hecker, R. Th. (1970). Palaeoichnological research in the Palaeontological Institute of the Academy of Sciences of the U.S.S.R. In: Trace Fossil (Ed. by T.P. Crimes & J.C. Harper). Geol. Jour. Spec. issue, 3, 215-226.

Heezen, B.C. (1955). Turbidity Currents from the Magdelena River, Columbia (Abst.): Geol. Soc. America Bull., 66, p.1572.

-------------- Menzies, R.J., Schneider, E.D., Ewing, W.M. & Grinelli, N.C. (1964). Congo submarine Canyon: Bull. Am. Ass. Petrol. Geol., 48, 1126-1149.

Heinberg, C. (1970). Some Jurassic trace fossils from Jameson Land (East Greenland). In: Trace Fossil (Ed. by T.P. Crimes & J.C. Harper). Geol. Jour. Spec.issue, 3, 227-234.

Helwig, J. (1970). Slump folds and early structures. J. Geol. 78, 172-187.

High, L.R. & Picard, M.D. (1974). Rehability of cross stratification types as palaeocurrent indicators in fluvial rocks. J. sedim. Petrol. 44, 158-68.

Hitchcock, E. (1858). Ichnology of New England; a report on the sandstone of the Connecticut valley, especially its footmarks. White, Boston, pp.220.

Holdsworth, B.K. (1963). Pre-fluvial, autogeosynclinal sedimentation in the Namurian of Central Pennines. Nature, 194, 133-5.

Hubert, J.F. (1966). Modification of the model for internal structures in graded beds to include a dune division. Nature, 211, 614-5.

Hudson, R.G.S. (1945). The Goniatite zones of the Namurian. Geol. Mag., 82, 1-9.

Hudson, R.G.S. & Black, W.W. (1940). A boring through the Kinderscout Grit -Group near Yeadon, Yorkshire. Trans. Leeds Geol. Assoc. 285.

--------------- & Cotton, G. (1943). The Namurian of Alport Dale, Derbyshire. Proc. Yorks. Geol. Soc., 25, 142-173.

Hull, E. (1864). The geology of the country around Oldham. Mem. Geol. Surv.

--------------- & Green, A.H. (1864). On the Millstone Grit of North Staffordshire and the adjoining parts of Derbyshire, Cheshire, and Lancashire. Q. Jl. Geol. Soc. London, 20, 242-67.

-------------- Dakyns, J.R., Tiddeman, R.H., Ward, J.C., Gun, W. & de Rance, C.E. (1875). Geology of the Burnley Coalfield. Mem. Geol. Surv. 225pp.

Jackson, R.G. (1978). Preliminary evaluation of lithofacies models for meandering alluvial streams. In: Fluvial Sedimentology (Ed. by A.D. Miall). Can. Soc. Petrol. Geol., Mem. 5, 543-576.

Johnson, E.W. (1981). A tunnel section through a prograding Namurian (Arnsbergian, E_{2a}) delta, in the western Bowland Fells, north Lancashire. Geol. Jl., 16, 93-110.

Jones, R.C.B. (1924). Summary of Progress. Mem. Geol. Surv.

Jones, O.T. (1936). On the sliding or slumping of submarine sediments in Denbighshire, North Wales, during the Ludlow Period (Abstract and discussion). Proc. geol. Soc. Lond., 1315, 110-5.

Jones, C.M. (1977). The sedimentology of Carboniferous Fluvial and Deltaic Sequences and Roaches Grit Group in the South West Pennines and Pennant Sandstone of the Rhondda Valleys. Unpublished Ph.D. Thesis, University of Keele, 206pp.

-------------- (1979). Tabular Cross-bedding in Upper Carboniferous Fluvial Channel Sediments in the southern Pennines, England. Sedim. Geol., 24, 85-104.

Jones, C.M. (1980). Deltaic Sedimentation in the Roaches Grit and associated Sediments (Namurian R_{2b}) in the south-west Pennines. Proc. Yorks. Geol. Soc., 43, No. 4, 39-67.

Jopling, A.V. (1963). Hydraulic studies on the origin of bedding. Sedimentology, 2, 115-21.

Kelling, G. (1968). Patterns of Sedimentation in Rhondda Beds of South Wales. Bull. Am. Ass. Petrol. Geol., 52, 2369-2386.

-------------- & George, G.T. (1971). Upper Carboniferous sedimentation in the Pembrokeshire Coalfield. In: Geological excursions in South Wales and the Forest of Dean (Ed. by D.A. Bassett & M.G. Bassett). 240-259. Geol. Ass. South Wales Group, Cardiff.

-------------- & Williams, B.P.J. (1966). Deformation structures of sedimentary origin in the Lower Limestone Shales (basal Carboniferous) of S. Pembrokeshire, Wales. J. Sedim. Petrol. 36, 927-939.

Kennedy, W.J. (1975). Trace fossils in Carbonate Rocks. In: The Study of Trace Fossils; A Synthesis of Principles, Problems and Procedures in Ichnology. (Ed. by R.W. Frey). 377-398, Springer-Verlag. Berlin. Heidelberg. New York.

Kepferle, R.C. (1978). Prodelta Turbidite fan apron in Borden Formation (Miss.), Kentucky & Indiana. In: Sedimentation in Submarine Canyons, Fans & Trenches: Dowden, Hutchinson & Ross, Pennsylvania (Ed. by D.J. Stanley & G. Kelling). 224-238.

Kerey, E. (1978). Sedimentological analysis of the Chatworth Grit (Namurian R_{2c}) in the Goyt-Chapel-en-le-Frith area. Unpublished M.Sc. Thesis, University of Keele.

Książkiewicz, M. (1970). Observations on the ichnofauna of the Polish Carpathians. In: Trace Fossils (Ed. by T.P. Crimes & J.C. Harper). 283-322.

Kuenen, P.H. (1964). The shell pavement below oceanic turbidites. Mar. Geol., 2, 236-46.

Lambert, A.M., Kelts, K.R. & Marshall, N.F. (1976). Measurements of density under flows from Walensee, Switzerland. Sedimentology, 23 87-105.

Lane, E.W. & E.W. Eden (1940. Sand waves in the lower Mississippi River. Jour. of the Western Soc. of Engineers, 45, 281-91.

Lowry, R.L. (1971). Stream bank failure and rotational slumping: preservation and significance in the geologic record. Bull. geol. Soc. Am., 82, 1251-1266.

Leblanc, R.J. (1972). Geometry of Sandstone Reservoir Bodies. Underground waste management and environmental implications. Am. Ass. Petrol. Geol. Mem. 18, 133-190.

Leopold, L.B. & M.G. Wolman (1957). River Channel patterns: braided, meandering and straight. Prof. Pap. U.S. Geol. Surv. 282-B, pp.85.

Lewis, K.B. (1971). Slumping on a continental slope inclined at 1^{o}-4^{o}. Sedimentology, 16, 97-110.

Mantz, P.A. (1978). Bedforms produced by fine, cohesionless, granular and flakey sediments under subcritical water flows. Sedimentology, 25, No.1, 83-103.

Marschalko, R. (1964). Sedimentary structures and palaeocurrents in the marginal lithofacies of the Central-Carpathian flysch. In: "Turbidites". (Ed. by A.H. Bouma & A. Brouwer), Elsevier, Amsterdam, 106-126.

Martinsson, A. (1965). Aspects of a Middle Cambrian thanatotype on Ölland. Geol. Fören. Stockholm Förh., 87, 181-230.

-------------- (1970). Toponomy of Trace Fossil. In: Trace Fossils (Ed. by T.P. Crimes & J.C. Harper). Geol. Jour. Spec. Issue No.3. 323-330.

Mayhew, R.W. (1967). A sedimentological investigation of the Marsdenian Grits and associated measures in Northwest Derbyshire. Unpublished Ph.D. Thesis, University of Sheffield.

McBride, E.F., Weide, A.E. & Wolleben, J.A. (1975). Deltaic and associated deposits of Difunta Group (Late Cretaceous to Palaeocene), Parras and La Popa Basins, northwestern Mexico. In: Deltas, Models for Explanation (Ed. by M.L. Brovssard), 485-522. Houston Geol. Soc. Houston.

McCabe, P.J. (1975). The Sedimentology and Stratigraphy of the Kinderscout Grit Group (Namurian, R_1) between Wharfedale and Longdendale. Unpublished Ph.D. Thesis, University of Keele, 172pp.

-------------- (1977). Deep distributary channels and giant bedforms in the Upper Carboniferous of the Central Pennines, northern England. Sedimentology, 24, 271-290.

-------------- & Jones, C.M. (1977). The formation of reactivation surfaces within superimposed deltas and bedforms. J. Sedim. Petrol., 47, 707-715.

McGowen, J.H. & Groat, C.G. (1971). Van Horn Sandstone, West Texas: an alluvial fan model for mineral exploration. Report of Investigation C, 72, pp. 57. Bureau of Econ. Geol. Univ. of Texas, Austin.

McKee, E.D. (1939). Some types of bedding in the Colorado River Delta. J. Geol., 47, 64-81.

-------------- (1957). Flume experiments on the production of stratification and cross stratification. J. Sedim. Petrol., 27, 129-134.

-------------- (1966). Significance of climbing-ripple structure. U.S. Geol. Surv. Profess. Papers 550-D, D94-D103.

-------------- Crossby, E.J. & Berryhill, H.L., Jr. (1967). Flood deposits, Bijou Creek, Colorado, June 1965. J. Sedim. Petrol., 37, 829-851.

Middleton, G.V. & Hampton, M.A. (1973). Sediment Gravity flows; mechanism of flow and deposition. In: Turbidites and deep water Sedimentation. Soc. econ. Paleont. Miner. Short Course, 1-38.

Moody-Stuart, M. (1966). High and low sinuosity stream deposits with examples from the Devonian of Spitsbergen, J. Sedim. Petrol. 36, 1102-17.

Moore, D. (1958). The Yoredale Series of Upper Wensleydale and adjacent parts of northwest Yorkshire. Proc. Yorks. geol. Soc., 31, 91-148.

-------------- (1960). Sedimentation units in sandstones of the Yoredale Series (Lower Carboniferous) of Yorkshire, England. J. Sedim. Petrol., 30, 218-227.

Moore, B.R. & Clark, M.K. (1970). The significance of a turbidite sequence in the Borden Formation (Mississippian) of eastern Kentucky and southern Ohio. In: Flysch Sedimentology in North America (Ed. by J. Lajoie). Geol. Assoc. Canada Spec. Paper 7, 211-18.

Morgan, J.P. (1970). Depositional Processes and Products in the Deltaic Environment. In: Deltaic Sedimentation; modern and ancient. (Ed. by J.P. Morgan). 31-47. Spec. Publ. Soc. Econ. Paleont. Miner., 15, Tulsa.

Morgan, J.P., Coleman, J.M. & Gagliano, S.M. (1968). Mudlumps: diapiric structures in Mississippi delta sediments. In: Diapirism and Diapirs. (Ed. by J. Braunstein and G.D. O'Brien), pp. 145-161.

Morgenstern, N. (1967). Submarine slumping and the initiation of turbidity currents. In: Marine Geotechnique (Ed. by A.F. Richards), pp. 189-220. Univ. Illinois Press, Urbana.

Nedeco (Netherlands Engineering Consultants) (1959). River Studies and Recommendations for Improvements of Niger and Benue. North-Holland, Amsterdam, pp.1000.

Nicholson, H.A. (1873). Contributions to the study of Errant Annelides of the older Palaeozoic rocks. Proc. R. Soc., 21, 228-90.

Okolo, S.A. (1982, in press). Fluvial distributary channels in the Fletcher Bank Grit (Namurian R_{2b}), at Ramsbottom, Lancashire, England. Spec. Publs. Int. Ass. Sediment, 6.

Oomkens, E. (1974). Lithofacies relations in the Late Quaternary Niger Delta Complex. Sedimentology, 21, 195-222.

Osgood, R.G. (1970). Trace fossils of the Cincinnati area. Palaeontographica Americana, 6, 281-444.

-------------- & Szmuc, E.J. (1972). The trace fossil Zoophycos as an indicator of water depth. Bull. Am. Paleontology, 62, No. 271. 22p.

Pelletier, R. (1958). Pocono palaeocurrents in Pennsylvania and Maryland. Bull. geol. Soc. Amer. 69, 1033-1064.

Phillips, J. (1836). Illustrations of the Geology of Yorkshire, Part 11. Mountain Limestone District. 253 pp. John Murray, London.

Piper, DJ.W. (1978). Turbidite Muds and Silts on Deep sea Fans and Abyssal Plains. In: Sedimentation in Submarine Canyons, Fans and Trenches (Eds. D.J. Stanley & G. Kelling), 163-176. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania.

Pollard, J.E. (1981). A comparison between the Triassic trace fossils of Cheshire and South Germany. Palaeontology, 24, Part 3, 555-588.

Potter, P.E. & Pettijohn, F.J. (1963). Palaeocurrents and basin analysis. 296pp, Springer-Verlag, Berlin.

Quatrefages, M.A. de (1849). Note sur la Scolicia prisca (A. De. Q.), Annelid fossile de la craie: Ann. Sci. Nat; Ser. 3, Zoologie, v.12, p.265-266.

Ramsbottom, W.H.C. (1966). A pictural diagram of the Namurian rocks of the Pennines. Trans. Leeds Geol. Ass., 7, 181-184.

-------------- (1969a). Interim report of the Namurian Working Group. C.R. Congr. int. Stratigr. Geol. Carb. (6th Sheffield, 1, 71-7.

-------------- (1969b). The Namurian of Britain. C.R. 6me Cong. int. Carb. Strat. Geol. (Sheffield 1967) 1, 219-32.

-------------- (1974). Namurian. In: "The Geology of the Mineral Resources of Yorkshire" (Ed. by D.H. Rayner & J.E. Hemingway), 73-87. Yorks. geol. Soc., Leeds.

-------------- (1977). Major Cycles of transgression and regression (mesothems) in the Namurian. Proc. Yorks geol. Soc. 41, 261-91.

-------------- (1979). Rates of transgression and regression in the Carboniferous of NW Europe. Jl. geol. Soc. Lond. 136, 147-153.

-------------- Rhys, G.H. & Smith, E.G. (1962). Boreholes in the Carboniferous rocks of the Ashover district, Derbyshire. Bull. geol. Surv. Gt. Br. 19, 75-168.

-------------- Calver, M.A., Eager, R.M.C., Hodson, F., Hothday, D.A., Stubblefield, J.C. & Wilson, R.B. (1978). A Correlation of Silesian Rocks in the British Isles. Geol. Soc. Spec. Report No. 10, 81pp.

Read, W.A. (1969). Fluviatile deposits in Namurian rocks of Central Scotland. Geol. Mag. 106, 331-347.

Read, H.H. & Watson, J. (1962). Introduction to Geology. Vol. 1, Principles. McMillan. London. 693pp.

Reading, H.G. (1964). A review of the factors affecting the sedimentation of the Millstone Grit (Namurian) in the Central Pennines. In: Deltaic and shallow marine deposits. (Ed. by L.M. J.U. van Straaten), Elsevier, Amsterdam. 340-6.

-------------- (1970). Sedimentation in the Upper Carboniferous of the Southern Flanks of the Central Cantebrian Mountains, Northern Spain. Proc. Geol. Assoc., 81, 1-41.

-------------- (1971). Sedimentation sequence in the Upper Carboniferous of Western Europe. C.r. 6e Congr. Intern. Strat. Geol. Carbonif., Sheffield, 1967, 4, 1401-1412.

Reineck, H.E. & Singh, I.B. (1975). Depositional Sedimentary Environments with reference to Terrigenous Clastics. Springer-Verlag. New York, Heidelberg, New York. 439pp.

Richter, R. (1850). Aus der thuringischen Grauwacke. Deutsch. Geol. Ges., 2, 198-206.

Rupke, N.A. (1978). Deep Clastic Seas. In: Sedimentary Environments and Facies (Ed. by H.G. Reading), 372-415. Blackwell Scientific Publications, Oxford.

Schumm, S.A. (1968). Speculations concerning Paleohydrologic Controls of Terrestial Sedimentation. Geol. Soc. Am. Bull., 79, 1573-1588.

Scott, A.J. & Fisher, W.L. Introduction to delta systems and deltaic deposition. In: Delta Systems in the Exploration for Oil & Gas (Ed. by W.L. Fisher, L.F. Brown, A.J. Scott & J.H. McGowen), 10-29. A Research Colloquium by Bur. Econ. Geol. Univ. of Texas, Austin.

Seilacher, A. (1953). Studien zur Palichnologie. 1. Über die Methoden der Palichnologie: Neues Jahrb. Geologie, Palaeotologie, Abhandl., 96, 421-452.

Seilacher, A. (1964a). Sedimentological classification and nomenclature of trace fossils. Sedimentology, 3, 253-256.

-------------- (1964b). Biogenic sedimentary structures. In: Approaches to Paleoecology. (Ed. by J. Imbrie & N.D. Newel), 296-316. John Wiley & Sons, Inc. (New York).

-------------- (1967). Bathymetry of trace fossils. Marine Geology 5, 413-428.

Sengupta, S. (1966). Studies on orientation and imbrication of pebbles with reference to cross-stratification. J. Sedim. Petrol. 36, 362-9.

Shackleton, J.S. (1962). Cross strata of the Rough Rock. (Millstone Grit Series) in the Pennines. Liverpool Manchester Geol. Jour. 3, 109-118.

Shephard, F.P. & Dill, R.F. (1966). Submarine Canyons and other Sea Valleys. pp.381. Rand McNally, New York.

Simons, D.B., Richardson, E.V. & Nordin, C.F. (1965). Sedimentary structures generated by flow in alluvial channels. In: Primary sedimentary structures and their Hydrodynamic Interpretation. (Ed. by G.V. Middleton). Spec. Publ. Soc. econ. Palaeont. Miner., Tulsa, 12, 34-52.

Simpson, S. (1970). Notes on Zoophycos and Spirophyton. In: Trace Fossils. (Ed. by T.P. Crimes & J.C. Harper), Geol. Jour. Spec. Issue No. 3, 505-514. Seel House Press (Liverpool).

Smith, W. (1819). New Geology Map of England and Wales. London. 1819-24.

Sorby, H.C. (1858, 1859). On the structure and origin of the Millstone Grit in South Yorkshire. Proc. Yorks. Geol. Soc., 3, 669-675.

Stanley, D.J., Krinitzsky, E.L. & Compton, J.R. (1966). Mechanics of Mississippi River bank failure in deltaic plain sediments at Fort Jackson, Louisiana. Bull. geol. Soc. Am., 77, 859-866.

Stephens, J.V., Edwards, W., Stubblefield, C.J. & Mitchell, G.H. (1942). The faunal divisions of the Millstone Grit Series of Rombalds Moor and neighbourhood. Proc. Yorks. Geol. Soc., 24, 344-372.

-------------- Mitchell, G.H. & Edwards, W. (1953). Geology of the country between Bradford and Skipton. Mem. Geol. Surv. 180pp.

Sunborg, A. (1956). The River Klarälven; A study in fluvial processes. Geograf. Ann. 38, 127-316.

Trotter, F.M. (1951). Sedimentation facies in the Namurian of north-west England and adjoining areas. Lpool. Manchr. Geol. J. 1, 77-112.

Walker, R.G. (1965). The origin and significance of the internal sedimentary structures of turbidites. Proc. Yorks. Geol. Soc. 35, 1-32.

-------------- (1966a). Shale Grit and Grindslow shales; transition from turbidite to shallow water sediments in the Upper Carboniferous of northern England. J. Sedim. Petrol. 36, 90-114.

-------------- (1966b). Deep channels in turbidite bearing formations. Bull. Am. Ass. Petrol. Geol. 50, 1899-1917.

Walton, E.K. (1967). The sequence of internal structures in turbidites. Scott. Jour. Geol., 3, 306-317.

Weimer, R.J. (1966). Time Stratigraphic Analysis and Petroleum Accumulations, Patrick Draw field, Sweetwater County, Wyoming. Bull. Am. Ass. Petrol. Geol., 50, No.10, 2150-2175.

Wentworth, C.K. (1922). A scale of grade and class terms for clastic sediments. J. Geol. 30, 377-92.

Whitehurst, J. (1778). An Enquiry into the original stab and formation of the Earth. London.

Williams, E. (1960). Intra-stratal flow and convolute folding. Geol. Mag. 97, 208-214.

Wilson, M.J. (1965). The origin and geological significance of the South Wales underclays. J. Sedim. Petrol., 35, 91-99.

Wood, A. (1936). Goniatite zones of the Millstone Grit Series in North Wales. Proc. Liverpoool Geol. Soc. 17, 10-28.

Woodcock, N.H. (1976a). Ludlow Series slumps and turbidites and the form of the Montgomery Trough, Powys, Wales. Proc. geol. Ass. 87, 169-182.

-------------- (1976b). Structural style in slump sheets: Ludlow Series, Powys, Wales. J. geol. Soc. Lond., 399-415.

-------------- (1979). The use of slump structures as palaeoslope orientation estimators. Sedimentology, 26, 83-99.

Wray, D.A., Stephens, J.V., Edwards, W.N. & Bromehead, C.E.N. (1930). The Geology of the country around Huddersfield and Halifax. Mem. Geol. Surv. H.M.S.O.

Wright, M.D. (1964). Cross bedding in the Millstone Grit of the Central Pennines and its significance. Geol. Mag. 101, 520-530.

-------------- (1967). Comparison of Namurian sediments of the Central Pennines, England, and recent deltaic deposits. Sediment. Geol., 1, 83-115.

Wright, W.B., Sherlock, R.L., Wray, D.A., Lloyd, W. & Tonks, L.H. (1927). The geology of the Rossendale Anticline. Mem. geol. Surv. Gt. Brit., H.M.S.O., London, 182pp.

Wunderlich, F. (1967). Die Entstehung von "convolute bedding" an Platenrändern. Senckenbergiana Lethaea, 48, 345-349.

Yochelson, E.L. & Schindel, D.E. (1978). A re-examination of the Pennsylvanian trace fossil Olivellites. Jour. Research U.S. Geol. Survey. 6, No. 6, 789-796.

A SEDIMENTOLOGIC -STRATIGRAPHIC INVESTIGATION OF MARSDENIAN (NAMURIAN R_{2A-B}) SEDIMENTS IN THE CENTRAL PENNINES

STEPHEN ANAGO OKOLO, M.S. KENTUCKY

1982

VOLUME 2: FIGURES AND PLATES

LIST OF FIGURES

Figure No.

1A. Stratigraphic location of the Marsdenian sediments

1B. Location of study area.

2A. Locality Map (East Part).

2B. Locality Map (West Part).

3. Structural Map.

4. The Marsdendian Goniatite Bands.

5. Location of areas and Cross Sections.

6. Occurrence and Distribution of Band of _R. gracile_ variants.

6B. Base map of Figure 6.

7. Occurrence and Distribution of Band of _R. bilingue_ early.

7B. Base map of Figure 7.

8. Occurrence and Distribution of Band of _R. bilingue_ typical.

8B. Base map of Figure 8.

9. Occurrence and Distribution of Band of _R. bilingue_ Late.

9B. Base map of Figure 9.

10. Occurrence and distribution of Band of _R. superbilingue_.

10B. Base Map of Figure 10.

11. Generalized section of the Marsdenian (Namurian R_{2AB}) Stage.

12. Stratigraphical section A-A1.

12B. Stratigraphical Section A-A1 showing interpreted palaeoenvironments.

13. Thickness distribution of Scotland Flags Interval.

14. Stratigraphical Section B-B1.

14B. Stratigraphical Section B-B1 showing interpreted palaeoenvironments.

15. Stratigraphical Section C-C1.

15B. Stratigraphical Section C-C1 showing interpreted palaeoenvironments.

16. Stratigraphical Section D-D1.

16B. Stratigraphical Section D-D1 showing interpreted palaeoenvironments.

17. Stratigraphical Section E-E1.

17B. Stratigraphical Section E-E1 showing interpreted palaeoenvironments.

18. Thickness distribution of Scotland Flags.

19. NW-SE Stratigraphical Section of Park Wood Quarry No. 1.

20. Vertical Section of Rag Clough.

21. Thickness distribution of Pule Hill Interval.

22. Thickness distribution of Pule Hill Grit.

23. Vertical Section of Chatterton Wood Sequence.

24. Pule Hill Grit Sequence at Warland Wood Quarries.

25. Thickness distribution of Hazel Greave Interval.

26. Thickness distribution of Hazel Greave Grit.

27. Isopach Map of the Marsdenian Sequence.

28. Fence diagram of the Marsdenian sediments.

29. Longworth Valley Vertical Section.

30. Slumped and unslumped horizons in Longworth Valley.

31. Thurst planes at Longworth Valley slump layer.

32. Orientation data from slump folds in Longworth Valley Exposure.

33. Processes that generated the slumping in Longworth Valley.

34. Rose plot showing multi-directional dips of Scotland Flags in Ramsden Clough.

35. Transverse intraset of angular foresets in Wicking Crag Quarry.

36. Internal erosion surface in Lumb Quarry.

37. Slumped and unslumped horizons in Riverside Cemetary Quarry.

38. Azimuthal plot of orientation of folds in Riverside Cemetary Quarry.

39. Stereonet plot of fold axis orientation in Riverside Cemetary Quarry.

40. Poles to axial surfaces in Riverside Cemetary Quarry.

41. Palaeocurrent pattern in unslumped sedimentary structures in Riverside Cemetary Quarry.

42. Traced sketch of large scale cross beds in Diggley Quarry.

43. Traced sketch of NW-SE face of Quarry in Ransden Clough, NW parts.

44. Traced sketch of NW-SE face of Quarry in Ramsden Clough, central parts.

45. Traced sketch of NW-SE face of Quarry in Ramsden Clough, SE parts.

46. Close up of parts of Figure 44.

47. Scour based sand bodies (channels) in Pule Hill (N-S face).

48. Stratification in the NW-SE face of Pule Hill.

49. Scour based sand bodies (channels) in Gorpley Clough.

50. Scour based sand bodies (channels) in Tower Hill Side.

51. Palaeocurrent plots of Pule Hill.

52. Vertical section of Wessenden Reservoir section.

53. Vertical section of Readycon Dean section.

54. Vertical section of Gorpley Clough section.

55. NE-SW stratigraphical section in Scotland Quarry.

56. Vertical section of Heyden Road exposures.

57. Vertical section of Scotland Flags in Ramsden Clough.

58. Delta model indicating typical arrangement of major components.

59. North-south stratigraphical section in Fletcher Bank Quarry.

60. Traced sketch of channels 1-4 in Fletcher Bank Quarry.

61. Alternate bar reconstruction in Fletcher Bank Channel 3.

62. Sketch diagram illustrating Fletcher Bank Channels 2 & 3 fill geometry.

63. Palaeocurrent histogram for Fletcher Bank Channel 3.

64. Model channel filling in Diggley Quarry.

65. Directional data in Diggley Quarry.

66. Field sketches of sedimentary structures relationships in Ramsden Clough.

67. Direction of dip of set boundaries in Fletcher Bank Channel 2.

68. Vertical section of Pule Hill Grit in Ramsden Clough.

69. Mechanisms for the formation of large-scale cross-beds.

70. Coset of Medium Scale and Large Scale Cross-beds in Hanging Stone Quarry.

71. Plan view of a straight channel with alternate bars.

72. Types of foresets and their associated eddies in Lithofacies 12.

73. Genesis of foresets and their internal erosion surfaces in Lithofacies 12.

74. Faults YY , XX , ZZ in NW-SE face of Wicking Crag Quarry.

75. Slumps in Wicking Crag Quarry.

76. Plot of orientation of folds in Wicking Crag.

77. Vertical section of Foster Clough.

78A. Vertical section of Cowloughton Clough.

78B. Vertical section of Harper Clough.

79. Vertical section of Buckden Clough.

80. Vertical section of Scout End.

81. Vertical section of Holmbridge Woodhouse Quarry.

82. Vertical section of Woodhouse Quarry.

83. Model of Minor Bar, Crevasse Channel Couplet.

84A. Palaeocurrent map of the whole of the eastern areas.

84B. Palaeocurrent map of the whole of the western areas.

85. Palaeogeographic map of the whole area at the end of the Scotland Flags Interval.

86. Paleogeographic map of the whole area at the end of Pule Hill Interval.

87. Paleogeographic map of the whole area at the end of Hazel Greave Interval.

88. Map of the whole area showing orientations of plants and *Pelecypodichnus*.

89. Model of Pule Hill delta in area 4.

90. Model of Scotland Flags delta in area 1.

91. Model of lobate delta, Lafourche type.

92. Toponomic classification of bioturbation structures (from Seilacher).

93. Toponomic classification of bioturbation structures (from Martinsson).

94. *Arenicolites* in Fletcher Bank.

95. *Arthrophycus* in Fletcher Bank.

96. *Gyrophyllites*, ?*Phycodes palmatum*, *Kouphichnium*, *Cochlichnus* in Park Wood Quarry.

97A. <ins>Palaeophycus</ins>, <ins>Planolites</ins>, <ins>Kouphichnium</ins> in Scout End Quarry.

97B. <ins>Palaeophycus</ins>, <ins>Planolites</ins>, <ins>Kouphichnium</ins> in Park Wood Quarry.

98. <ins>Palaeophycus</ins> in Fletcher Bank Quarry.

99. <ins>Phycodes</ins> <ins>Curvipalmatum</ins> in Wicking Crag Quarry.

100. <ins>Phycodes</ins> <ins>Curvipalmatum</ins> (complex tubes) in Wicking Crag Quarry.

101. Distribution of trace fossils in the whole area.

LIST OF PLATES

Plate No.

1. Lower Parts of Scotland Flags at Scotland Flags Quarry.

2. Top Parts Plate 1.

3. Lower Parts of Scotland Flags at Foster Clough Quarry.

4. Top parts of Plate 3.

5. Coal on Seatearth in Park Wood Quarry 1.

6. Rock Sequence in Park Wood Quarry 1.

7A. Parallel Sided Sandstone in Woodhouse Quarry.

7B. Parallel Sided Sandstone in Foster Clough.

8. Thickly bedded sandtone in Pule Hill.

9. Olivellites at bedding planes of Horizontal beds in Bare Clough.

10A. Symmetrical ripples at top of sandstone in Park Wood Quarry 3.

10B. Symmetrical ripples at base of sandstone in Park Wood Quarry 3.

11. Siliceous ferruginous claystone nodules.

12. Siliceous ferruginous claystone bands.

13. Sandstone beds with gradational basal boundary in Holmbridge Woodhouse.

14. Sandstone beds with gradational basal boundary in Holmbridge Woodhouse.

15. Thick siltstone units in Rake Dike.

16. Tabular beds of siltstone alternating with mudstone in Sunny Bank Cutting.

17. Convolute bedding in siltstone in Fletcher Bank Quarry.

18. Slumped and unslumped horizons in Longworth Valley.

19. Slump at Longworth Valley (South Parts).

20. Slump at Longworth Valley (North Parts).

21. Slump at Longworth Valley.

22. Connected lenticles of lithofacies 7, Fletcher Bank Quarry.

23. Climbing ripples in lithofacies 7, Harper Clough Quarry.

24. Symmetrical ripples in lithofacies 7, Harper Clough Quarry.

25. Sandstone lenticles of lithofacies 7, "floating" in Siltstone, Fletcher Bank Quarry.

26. Siltstone layer as parting between lithofacies 7, Fletcher Bank Quarry.

27. Crescentric pattern of lithofacies 8 in plan view, Heyden Road Exposure.

28. Trough Cross Bedded Sandstone as transverse intraset of angular foresets, Wicking Crag Quarry.

29. Destruction of Trough Cross Lamination by Pelecypodichnus, Warland Wood Quarries.

30. Lithofacies 9 in Scotland Quarries.

31. Ball and Pillow in Light Hazzles Clough.

32. Pebbles in lithofacies 10, Braithwaite Quarry.

33. Mud Conglomerates and plants in Lithofacies 10, Ponden Clough.

34. Logs of Wood in lithofacies 10, Woodhouse Quarry.

35. Planar laterally extensive boundary surfaces of lithofacies 10 in Park Wood Quarry.

36. Concave upward bases of lithofacies 10, Clough Road Exposure.

37. Set boundaries of lithofacies 10, dipping perpendicular to palaeocurrent trend, Fletcher Bank.

38. Sinuous dunes in Harper Clough Quarry.

39A. East-west section in Branshaw Quarry.

39B. Northeast-southwest section in Branshaw Quarry.

40. Tree trunk in growth position in Harper Clough Quarry.

41. Pitted interval structure of the roots in Plate 40.

42. Co-existence of Trough and Tabular Sets of Cross Beds, Pule Hill.

43. Logs of wood in lithofacies 11, Fletcher Bank Quarry.

44. Tabular Cross Bedded Sandstone with angular foresets, Buckden Clough.

45. Tabular Cross Bedded Sandstone with tangential foresets, Triangle Railway Cutting.

46. Tabular Cross Bedded Sandstone with concave upward foresets, Esholt Railway Cutting.

47. Mud clasts aligned along cross-bedding planes, Bracken End Quarry.

48. Low angle foresets in lithofacies 11, Triangle Railway Cutting.

49. Slumped and unslumped horizons, Riverside Cemetary Quarry, Sowerby Bridge.

50. Partly deformed Climbing Ripples, Riverside Cemetary Quarry, Sowerby Bridge.

51. Overturned and recumbent folds at middle parts, Riverside Cemetary, Sowerby Bridge.

52. Inclined folds at southwest end, Riverside Cemetary Quarry.

53. Large-scale cross-beds in Diggley Quarry.

54. Large-scale cross-beds in Tower Hill side.

55. Large-scale cross-beds with concave upwards foresets, Park Wood Quarry 3.

56. Large-scale cross-beds with gradational base, Park Wood Quarry 2.

57. Mudstone drape in large-scale cross-beds in Diggley Quarry.

58. Sigmoidal foresets, Kebroyd Quarry.

59. Internal erosion surface, Ramsden Clough.

60. NW-SE face of Quarry in Ramsden Clough, NW parts.

61. NW-SE face of Quarry in Ransden Clough, Central parts.

62. NW-SE face of Quarry in Ramsden Clough, SE parts.

63. Close up of Parts of Plate 61.

64. Scour based sand bodies, Wicking Crag.

65. Scour based sand bodies, Riverside Cemetary Quarry, Sowerby Bridge.

66. Logs of Wood at base of scour based sand bodies, Tower Hill side.

67. Logs of wood at base of scour based sand bodies, Wicking Crag.

68. Quartz and mud conglomerate at base of scour based sand bodies in Tower Hill side.

69. Mud conglomerate at base of scour based sand bodies in Gorpley Clough.

70. Thin shale and coalified wood at base of scour based sand bodies in Wicking Crag.

71. Coalified wood at base of scour based sand body, Tower Hill side.

72. Symmetrical cross-strata of scour based sandbodies, Riddlesden Quarry.

73. Scour based sand bodies in N-S face of Pule Hill Quarry.

74. Symmetrical cross-beds of scour based sand bodies in Riverside Cemetary Quarry.

75. Asymmetrical cross-beds in scour based sand bodies in Fletcher Bank.

76A. NE-SW face of Riddlesden Quarry.

76B. Trough cross bed intraset, Lower Scour based sand body, Riddlesden Quarry.

77. NW-SE face of Quarry at Pule Hill showing channels.

78. Horizontal bedded sandstone in Diggley Quarry.

79. Scoured base of horizontal bedded sandstone in Readyshore Scout.

80. Trough based unit within horizontal bedded sandstone in Bare Clough.

81. Load at scoured base of horizontal bedded sandstone in Ponden Clough.

82A. Lenticular sandstone beds at Fletcher Bank Quarry (level 26-28m).

82B. Lecticular sandstone beds at Fletcher Bank Quarry (level 41-42m).

82C. Lenticular sandstone beds at Fletcher Bank Quarry (level 46-50m).

83. Lenticular sandstone beds in Readyshore Scout.

84. Lenticular sandstone beds in Holmbridge Woodhouse Quarry.

85. Sinusoidal ripples in Ramsden Clough.

86. Plan of relationship between accretion dip direction and current flow direction, Pule Hill.

87. Lag deposits (pebbles, plants, sandstone and siltstone blocks), Ponden Clough.

88. Erosive base of massive sandstone, Heyden Road exposure.

89. Pinch and swell sandbodies, Hazel Greave type section.

90. Flutes at base of turbidite-like sandstone, Gorpley Clough.

91. Longitudinal furrows and ridges, Gorpley Clough.

92A. Prod and bounce marks, Gorpley Clough.

92B. Prod and bounce marks, Gorpley Clough.

93A. Load structure at base of turbidite-like sandstone, Gorpley Clough.

93B. Sole marks at base of turbidite-like sandstone, Gorpley Clough.

94. Vertically oriented rootlets, Warland Wood Quarries.

95. Horizontally oriented _in-situ_ stigmaria, Warland Wood Quarries.

96. Stigmaria roots and rootlets, Fletcher Bank Quarry.

97. Stigmaria roots and rootlets, Fletcher Bank Quarry.

98. Escape shafts of _Pelecypodichnus_ and rootlets, Cowloughton Clough.

99. Vegetable rich coal (Type B coal), Cowloughton Clough.

100. Goniatite in Sunny Bank cutting.

101A. Base of Fletcher Bank Channel 1.

101B. Base of Fletcher Bank Channel 1.

102. Central and southern parts of Fletcher Bank Quarry showing channels 1-4.

103. Steep erosional base of Channel 4 of Fletcher Bank Quarry.

104. Groove at base of Fletcher Bank's channel 2.

105. Dumped wood at base of sheet sandstone, Bracken End.

106. Dumped wood at base of sheet sandstone, Carlton Lane.

107. Abundant mudstone clasts at base of sheet sandstone, Readyshore Scout.

108. NW-SE face, Wicking Crag.

109. Slump at Wicking Crag.

110. Slump at Wicking Crag (close-up of NW parts of Plate 109).

111. _Pelecypodichnus_ bump at sandstone base, Harper Clough.

112. Stigmaria root at Woodhouse Quarry.

113. Channel in mouth bar area (Pule Hill Grit), Ramsden Clough.

114. _Arenicolites_, Fletcher Bank Quarry.

115. _Arenicolites_ with funnel. Fletcher Bank Quarry.

116. _Arenicolites_ with truncated tops, Fletcher Bank Quarry.

117A. _Arenicolites_ with one limb wider than the other limb. Fletcher Bank Quarry.

117B. _Arenicolites_ with one limb wider than the other limb. Fletcher Bank Quarry.

118. _Arthrophycus_, Fletcher Bank.

119. _Gyrophyllites_, ?_Phycodes palmatum_, _Kouphichnium_, _Cochlichnus_, Park Wood Quarry 3.

120. _Gyrophyllites G_locker, Park Wood Quarry 3.

121A. _Kouphichnium rossendalensis_ (solitary form).

121B. _Kouphichnium rossendalensis_ (group).

122. Palaeophycus, Fletcher Bank Quarry.

123. Palaeophycus, Scout End Quarry.

124A. Cubichnia of Pelecypodichnus (convex hyporelief), Scotland Flags Quarry.

124B. Cubichnia of Pelecypodichnus (concave epirelief), Scotland Flags Quarry.

124C. Domichnia of Pelecypodichnus (endichnial shaft), Castle Carr Quarry.

125. Pelecypodichnus in Fletcher Bank Quarry.

126A. Endichnia of Olivellites and Pelecypodichnus (positive feature, Rake Dike.

126B. Endichnia of Olivellites and Pelecypodichnus (negative feature) Rake Dike.

127. Cubichnia of Pelecypodichnus, Harper Clough Quarry.

128. Pelecypodichnus bump with rough surface, Branshaw Quarry.

129. Unoriented cubichnia of Pelecypodichnus in Ramsden Clough.

130. Highly organized Pelecypodichnus, Foster Clough Quarry.

131. Domichnia of Pelecypodichnus (length 35cm), Branshaw Quarry.

132. Domichnia of Pelecypodichnus showing highly inclined escape shafts axes, Scotland Quarry.

133. Domichnia of Pelecypodichnus in Castle Car with the longest (46cm) escape shaft.

134. Fodinichnia of Phycodes curupalmatum Wicking Crags Quarry.

135. Fodinichnia of Phycodes curupalmatum Wicking Crags Quarry. cf. Nereites arrowed.

136. Planolites.

137. Olivellites in Readyshore Scout.

138A. Olivellites, Ponden Clough.

138B. Olivellites, Ponden Clough.

139. Paths of Olivellites seen in vertical section Ponden Clough.

140. Paths of Olivellites seen in vertical section Ponden Clough.

141. Repichnia of Olivellites in Bare Clough.

142A. Repichnia of Olivellites in Rag Clough (negative feature).

142B. Repichnia of Olivellites in Rag Clough (positive feature).

143A. Scolicia in Park Wood Quarry 3.

143B. Scolicia in Park Wood Quarry 3.

144A. Zoophycos (negative feature) Ponden Clough.

144B. Zoophycos (positive feature) Ponden Clough.

145. Loop trails (epichnial ridge) Fletcher Bank Quarry.

146A. Sinuous trails (positive feature) Light Hazzles Clough.

146B. Sinuous trails (negative feature) Light Hazzles Clough.

SECTION I. FIGURES

Fig. 1A.

Stratigraphical Position of the Marsdenian Sediments.

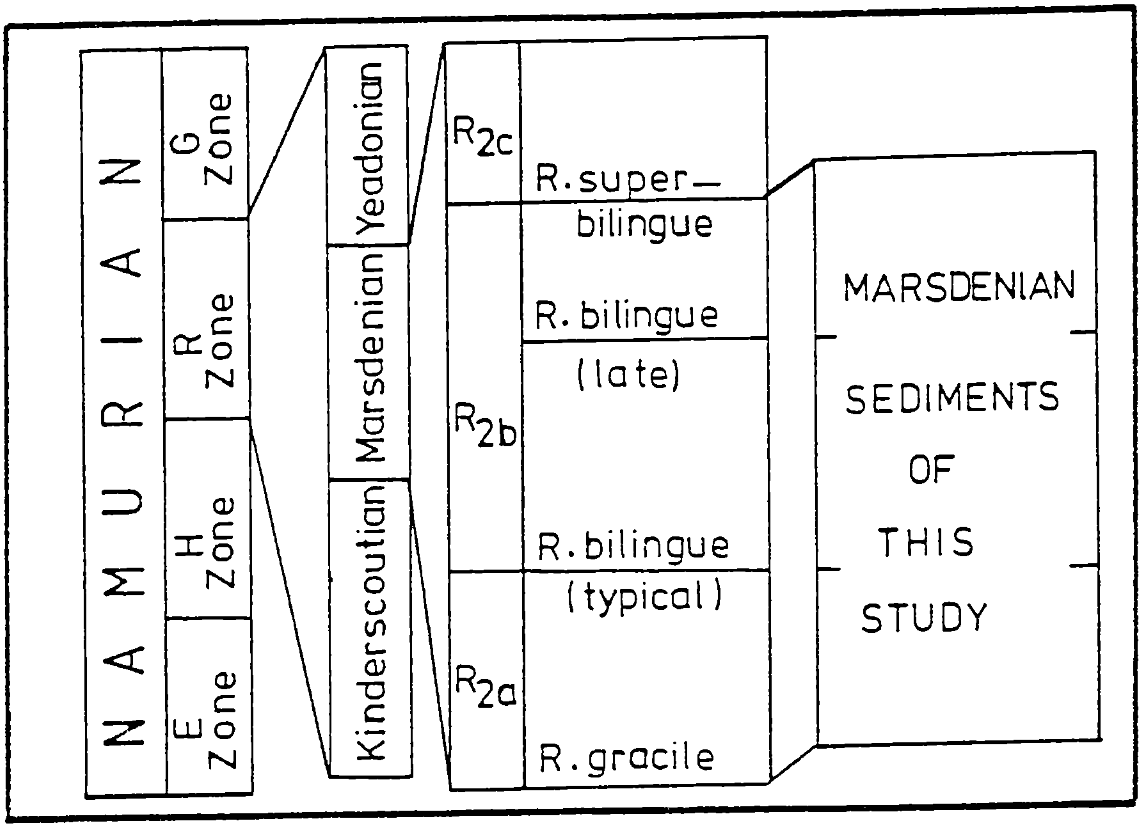
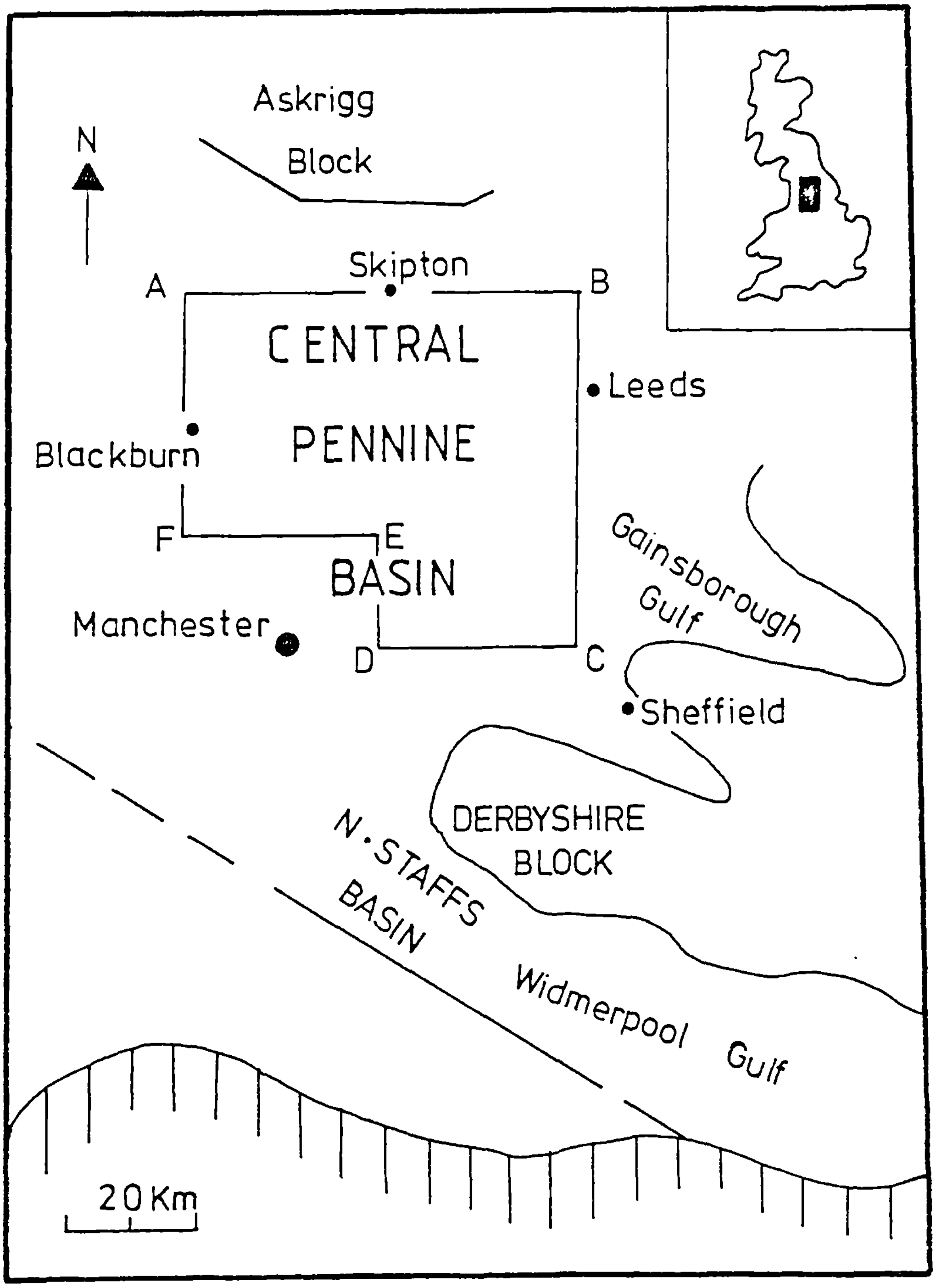
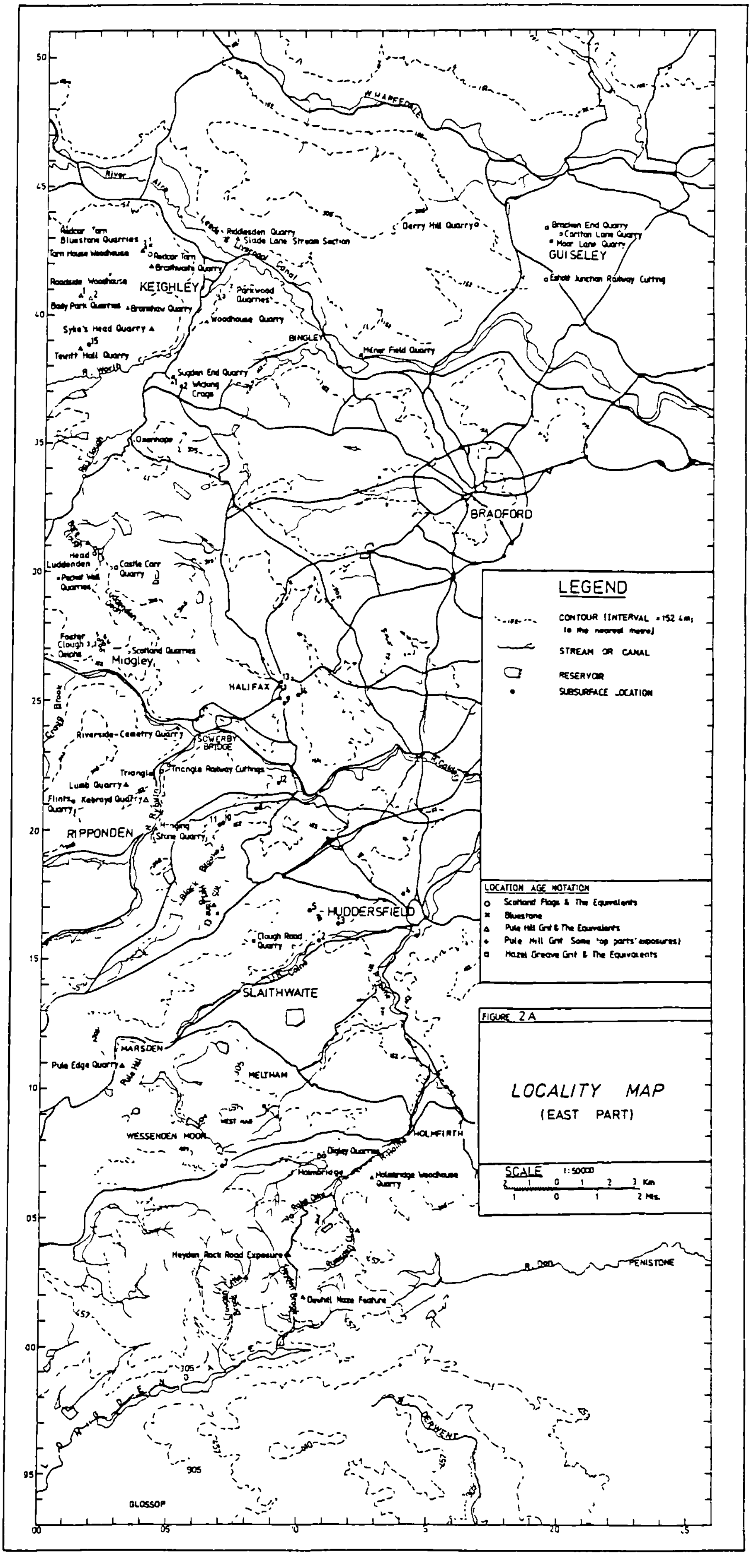

NAMURIAN
G Zone
R Zone
H Zone
E Zone
Yeadonian
Marsdenian
Kinderscoutian
R_{2c}
R_{2b}
R_{2a}
R. superbilingue
R. bilingue (late)
R. bilingue (typical)
R. gracile
MARSDENIAN
SEDIMENTS OF THIS STUDY

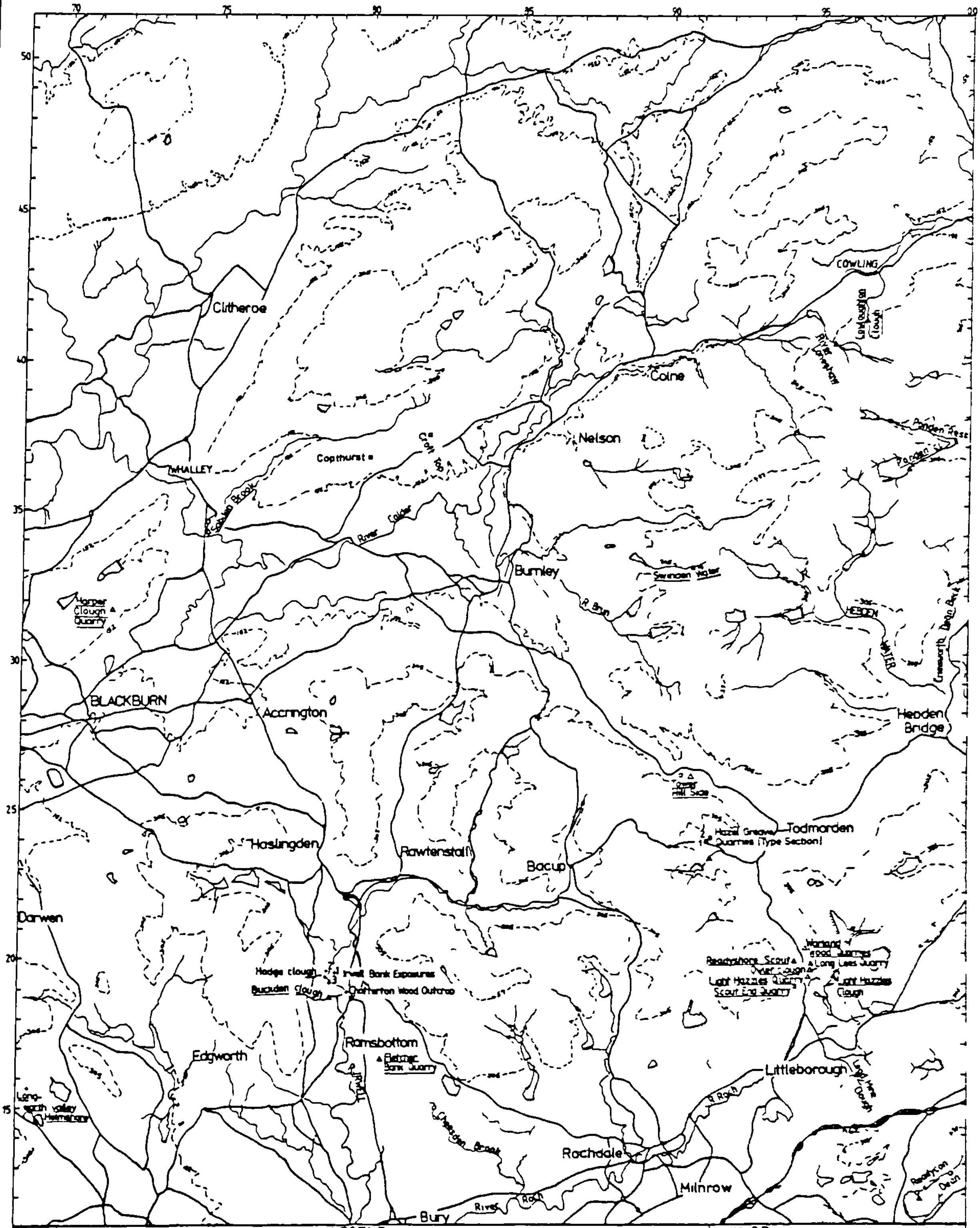
Fig. 1B.

Location of study area (ABCDEF) in relation to the major Carboniferous structural elements.


Askrigg
Block
N
Skipton
A
B
CENTRAL
Leeds
Blackburn
PENNINE
F
E
BASIN
Gainsborough
Gulf
Manchester
D
C
Sheffield
DERBYSHIRE
BLOCK
N·STAFFS
BASIN
Widmerpool
Gulf
20 Km



LEGEND
CONTOUR (INTERVAL = 152.4m; to the nearest metre)
STREAM OR CANAL
RESERVOIR
SUBSURFACE LOCATION
LOCATION AGE NOTATION
Scotland Flags & The Equivalents
Bluestone
Pule Hill Grit & The Equivalents
Pule Hill Grit Some 'top parts' exposures)
Hazel Greave Grit & The Equivalents
FIGURE 2A
LOCALITY MAP
(EAST PART)
SCALE 1:50000
3 1 0 1 2 3 Km
1 0 1 2 Mls.
R. WHARFE
River Aire
Leeds Liverpool Canal
KEIGHLEY
GUISELEY
BINGLEY
BRADFORD
HALIFAX
SOWERBY BRIDGE
Midgley
RIPPONDEN
HUDDERSFIELD
SLAITHWAITE
MARSDEN
MELTHAM
WESSENDEN MOOR
HOLMFIRTH
Holmbridge
PENISTONE
GLOSSOP
R. Don
R. DERWENT
Redcar Tarn
Bluestone Quarries
Tarn House Woodhouse
Redcar Tarn
Brackwaite Quarry
Roadside Woodhouse
Baily Park Quarries
Bransaw Quarry
Syke's Head Quarry
Tewitt Hall Quarry
R. Worth
Riddlesden Quarry
Slade Lane Stream Section
Parkwood Quarries
Woodhouse Quarry
Derry Hill Quarry
Bracken End Quarry
Carlton Lane Quarry
Moor Lane Quarry
Esholt Junction Railway Cutting
Milner Field Quarry
Sugden End Quarry
Wicking Crags
Oxenhope
Luddenden
Castle Carr Quarry
Pecket Well Quarries
Foster Clough Delphs
Scotland Quarries
Crag Brook
Riverside-Cemetery Quarry
Triangle
Triangle Railway Cuttings
Lumb Quarry
Flints Quarry
Kebroyd Quarry
Hanging Stone Quarry
Black Brook
Clough Road Quarry
Pule Edge Quarry
Pule Hill
West Nab
Digley Quarries
Holmbridge Woodhouse Quarry
Heyden Rock Road Exposure
Dewhill Naze Feature
50
45
40
35
30
25
20
15
10
05
00
95
00
05
10
15
20
25



LOCATION AGE NOTATION	
o	Scotland Flags & The Equivalents
x	Bluestone
▲	Pule Hill Grit & The Equivalents
+	Pule Hill Grit (Some top parts' exposures)
a	Hazel Greave Grit & The Equivalents

LEGEND

--152--	Contour (Interval = 152.4m to the nearest metre)
——	Road
~~	Stream
▭	Reservoir

FIGURE 28

LOCALITY MAP

(WEST PART)

SCALE 1:50,000

2 1 0 1 2 3 Kilometres

1 0 1 2 Miles

Fig. 3.

Map showing the main structural features of the study area.

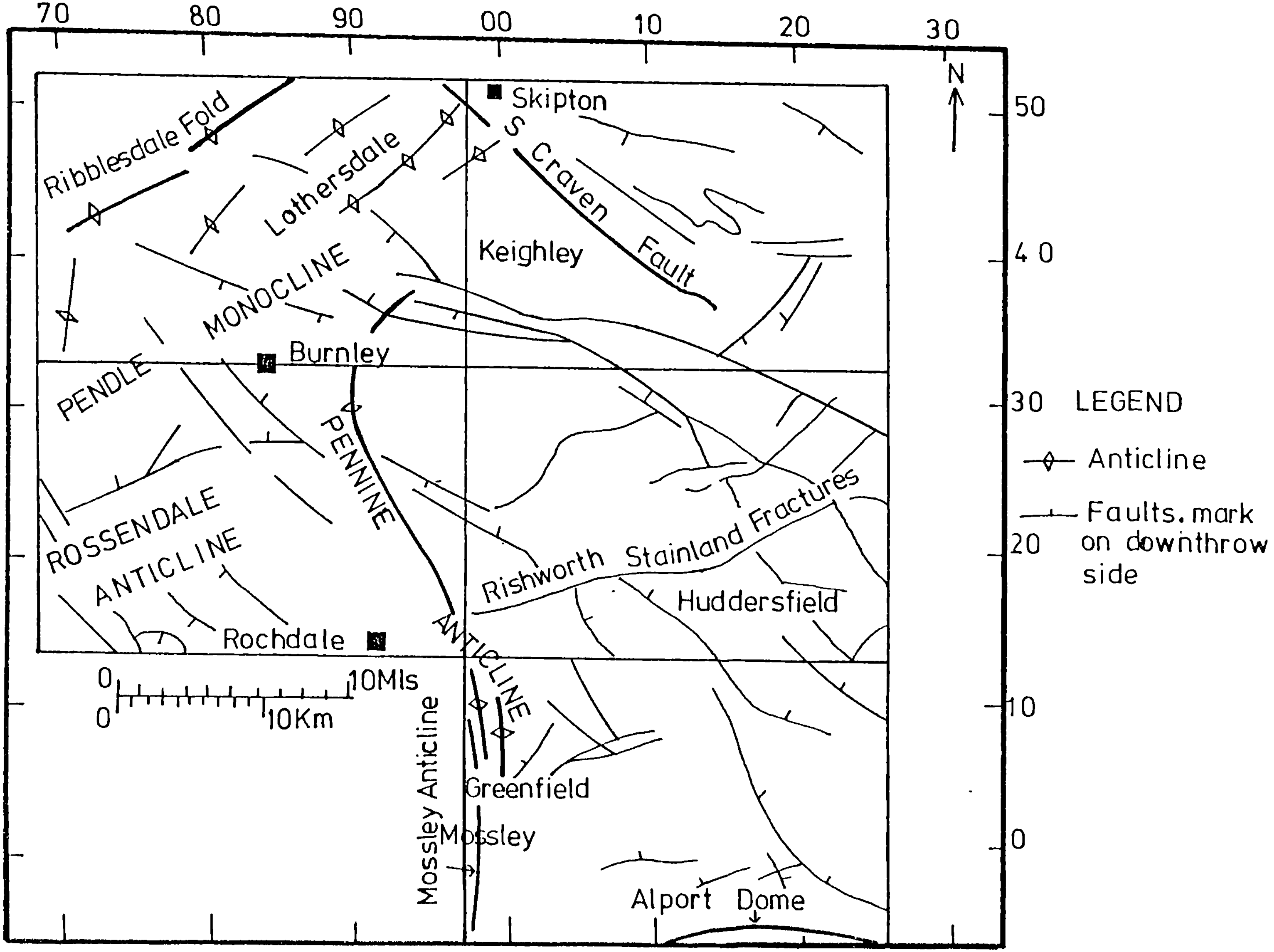
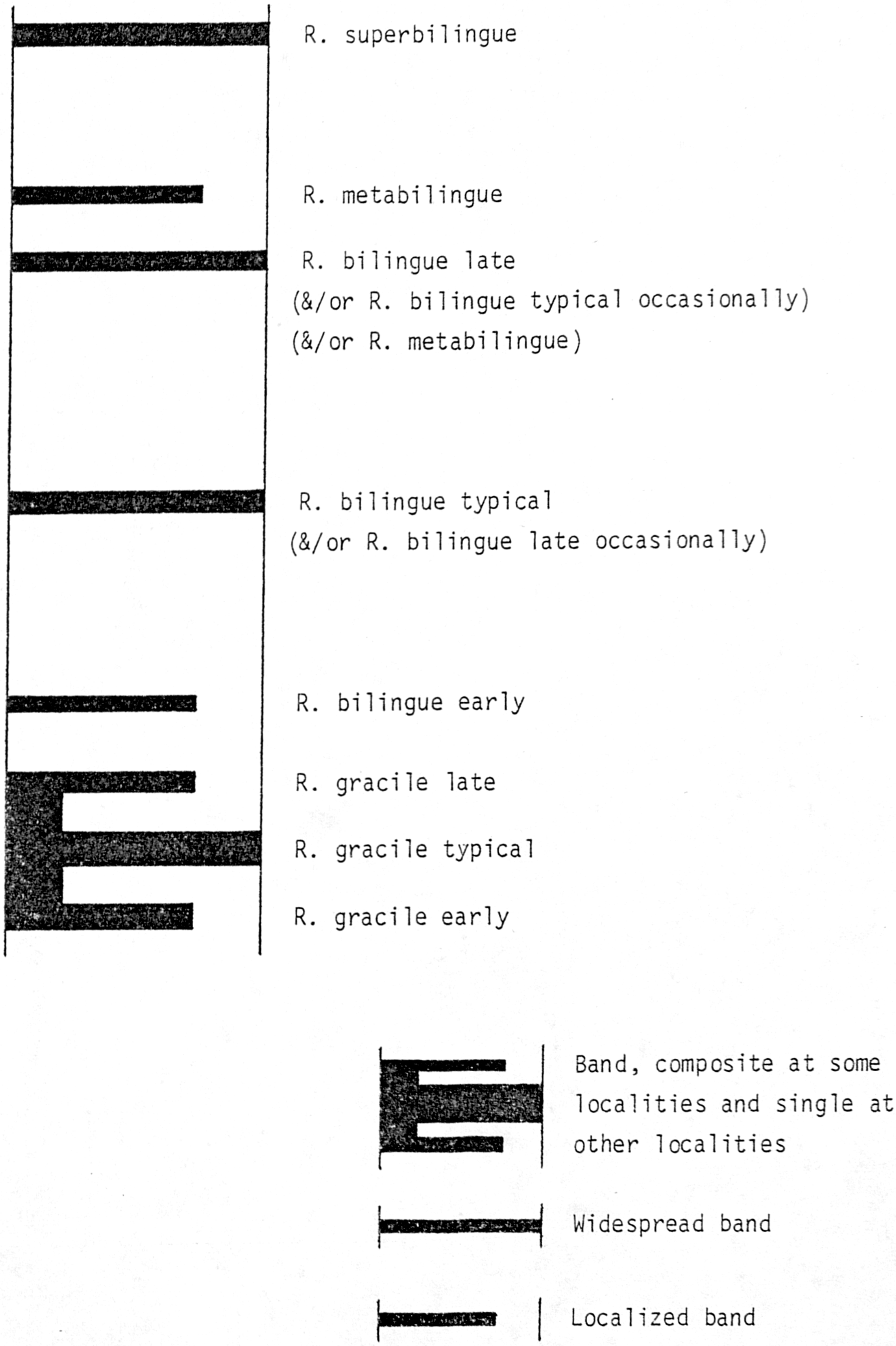

70
80
90
00
10
20
30
50
4 0
30
20
10
0
N
Skipton
S
Craven Fault
Keighley
Ribblesdale Fold
Lothersdale
MONOCLINE
Burnley
PENDLE
PENNINE
ROSSENDALE
ANTICLINE
Rochdale
ANTICLINE
Rishworth Stainland Fractures
Huddersfield
0
10Mls
0
10Km
Mossley Anticline
Greenfield
Mossley
Alport Dome
LEGEND
Anticline
Faults. mark on downthrow side

Fig. 4. THE MARSDENIAN GONIATITE BANDS



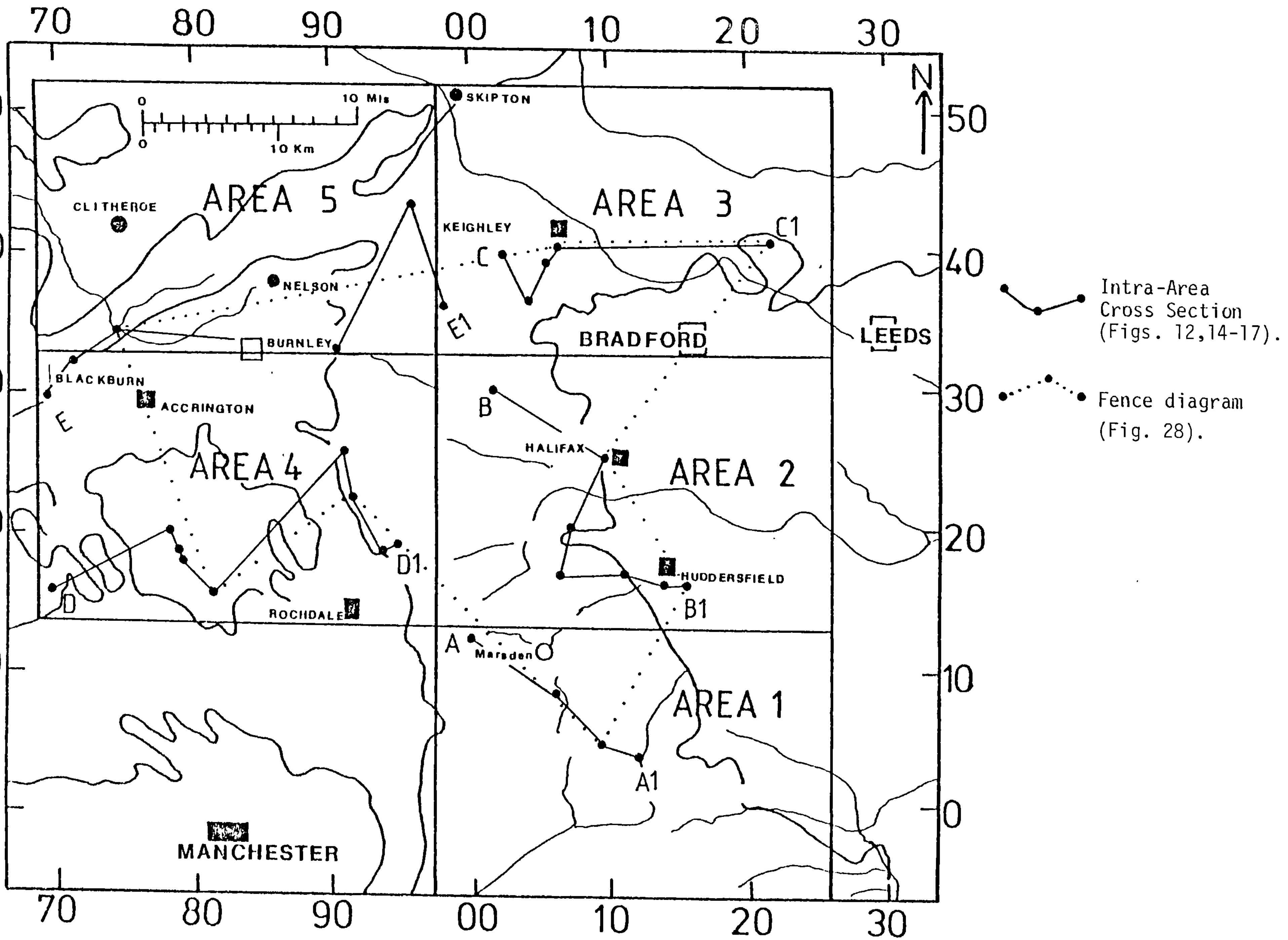
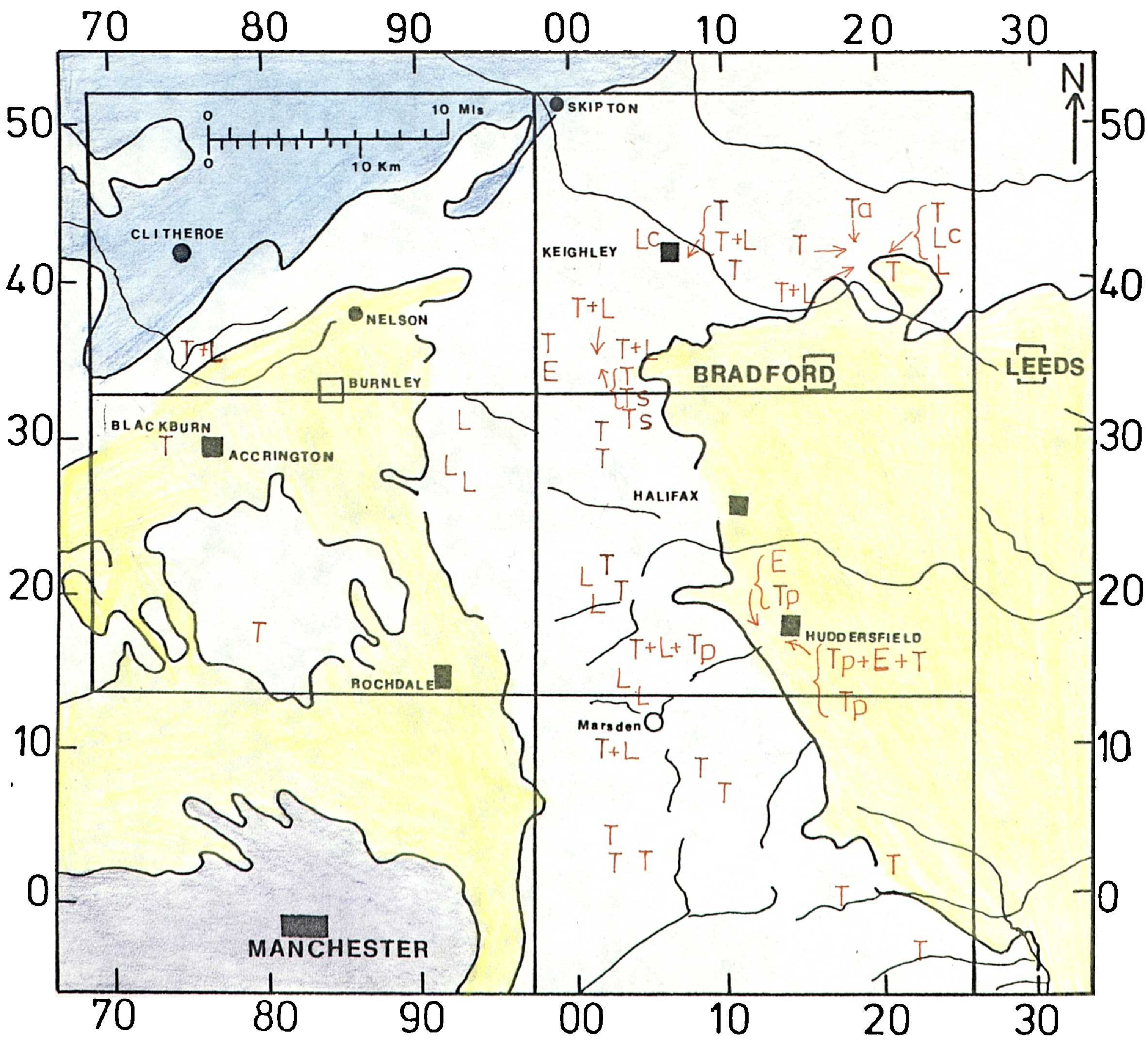


FIG 5. LOCATION OF AREAS AND CROSS-SECTIONS.

Fig. 6.

Occurrence and Distribution of Band of _R_. _gracile_ variants.

Yellow	(West Parts)	....	....	Burnley Coalfield (Westphalian).
Yellow	(East Parts)	....	....	West Yorkshire Coalfield (Westphalian).
Blue		....	....	Mainly Limestone (Lower Carboniferous).
Purple		....	....	Permo-Trias.



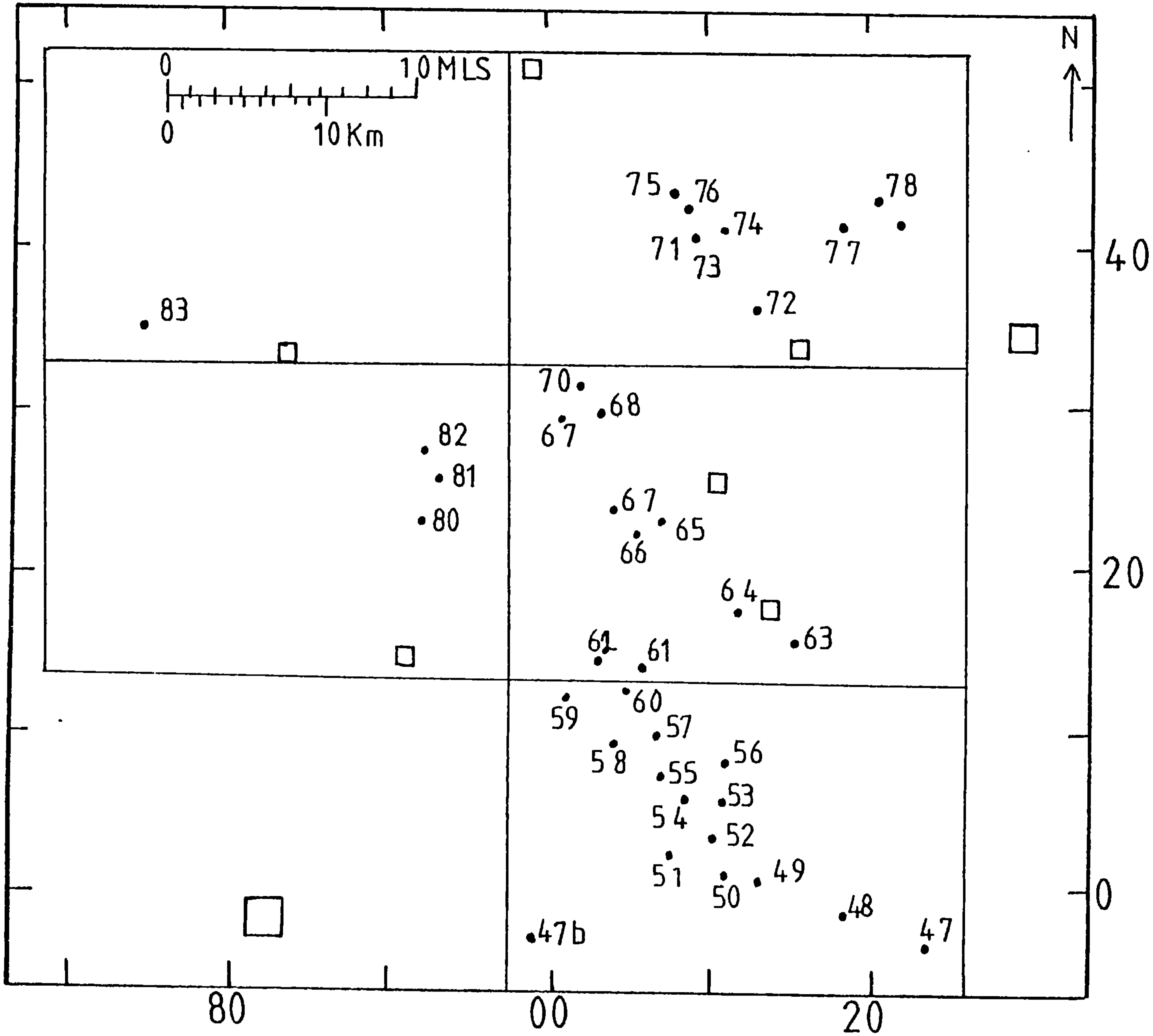
LEGEND

L	Late
T	Typical
E	Early
Tp	Type
Ta	aff gracile
Lc	cf Late
Ts	Gracile s.l.
+	Coexistence
{	Composite Band
....	uppermost band
....	middle band
....	lowermost band
→	Indicates Location
Me	Metabilingue
Ln	Lingula
G	Gastrioceras lineatum
S	Gastrioceras ? sigma
M	Undifferentiated marine fossils

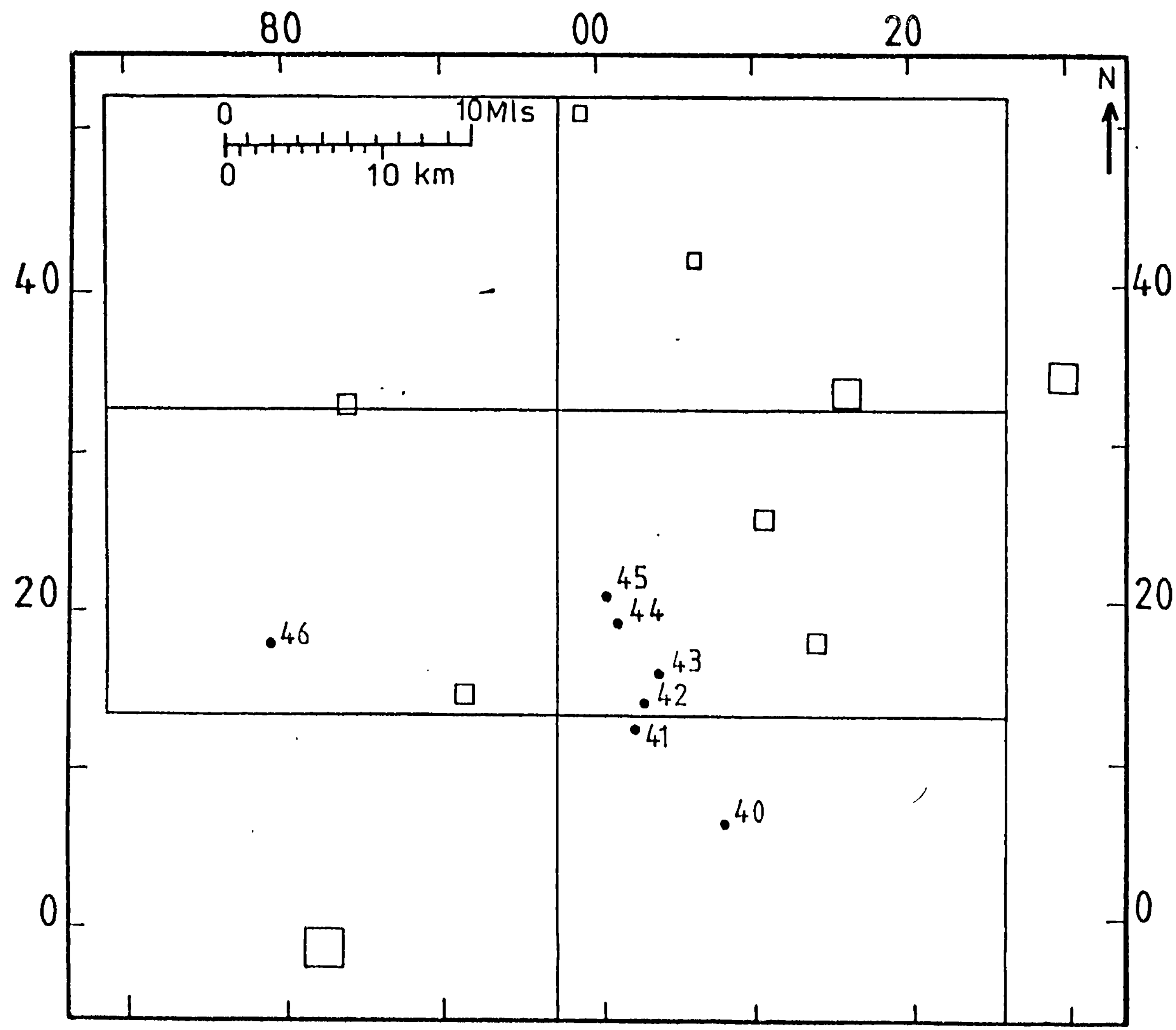
Fig. 6B.

Base Map of Figure 6, showing localities of occurrence of bands of *R. gracile* variants.

Numbered localities are listed in Table 3A and 3B pages 32 and 33.



N
0
10 MLS
0
10 Km
75
76
74
78
71
73
77
72
83
70
68
67
82
81
80
67
65
66
64
63
61
61
60
59
57
56
58
55
53
54
52
51
49
50
48
47b
47
40
20
0
80
00
20

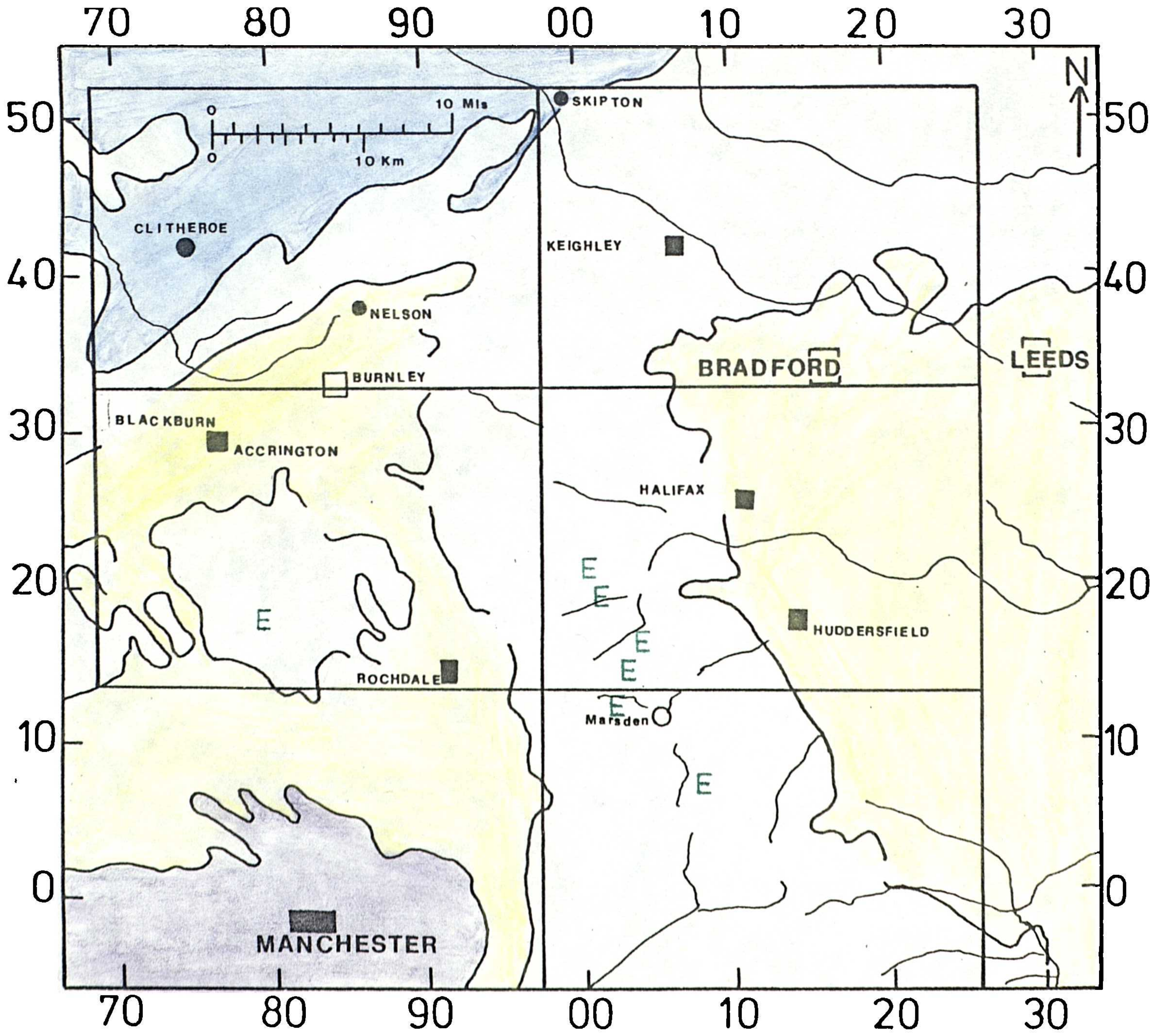


80
00
20
40
20
0
N
0
10Mls
0
10 km
45
44
43
42
41
40
46

Fig. 7.

Occurrence and Distribution of Band of _R_. _bilingue_ early.

Yellow (West Parts)	....	....	Burnley Coalfield (Westphalian).
Yellow (East Parts)	....	....	West Yorkshire Coalfield (Westphalian).
Blue	....	....	Mainly Limestone (Lower Carboniferous).
Purple	....	....	Permo-Trias.



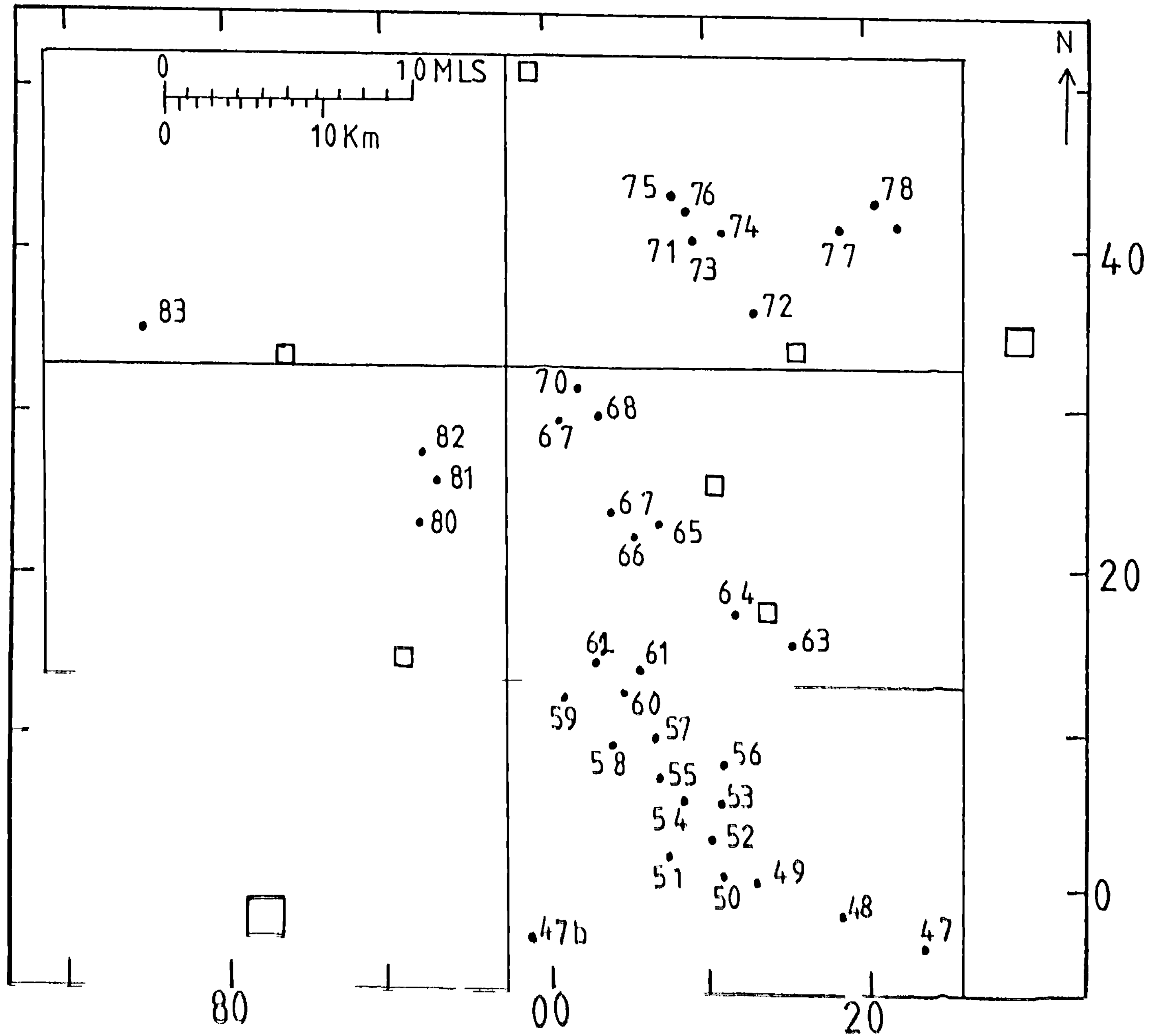
LEGEND

L	Late
T	Typical
E	Early
Tp	Type
Ta	aff <u>gracile</u>
Lc	cf Late
Ts	<u>Gracile</u> s.l.
+	Coexistence
{	Composite Band
····	uppermost band
····	middle band
····	lowermost band
→	Indicates Location
Me	<u>Metabilingue</u>
Ln	<u>Lingula</u>
G	<u>Gastrioceras lineatum</u>
S	<u>Gastrioceras ? sigma</u>
M	Undifferentiated marine fossils

Fig. 7B.

Base Map of Fig. 7, showing localities of occurrence of band of *R. bilingue* early.

Numbered localities are listed in Table 4, page. 36.

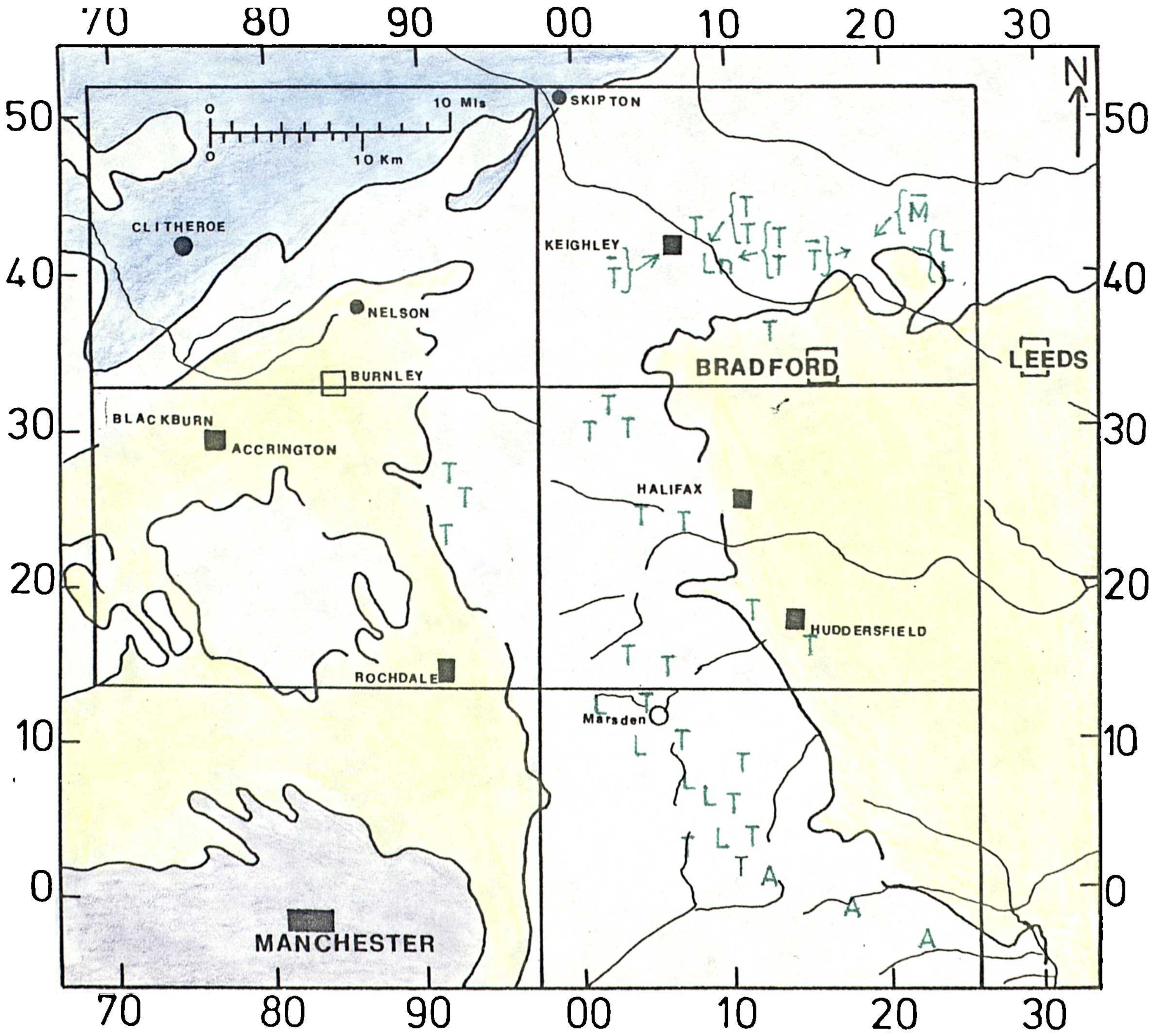


N
0
10 MLS
0
10 Km
75
76
74
78
71
73
77
72
83
70
68
67
82
81
80
67
65
66
64
63
61
61
60
59
57
56
58
55
53
54
52
51
49
50
48
47
47b
40
20
0
80
00
20

Fig. 8.

Occurrence and Distribution of Band of *R. bilingue*, typical.

Yellow (West Parts)	....	....	Burnley Coalfield (Westphalian).
Yellow (East Parts)	....	....	West Yorkshire Coalfield (Westphalian).
Blue	....	....	Mainly Limestone (Lower Carboniferous).
Purple	....	....	Permo -Trias.



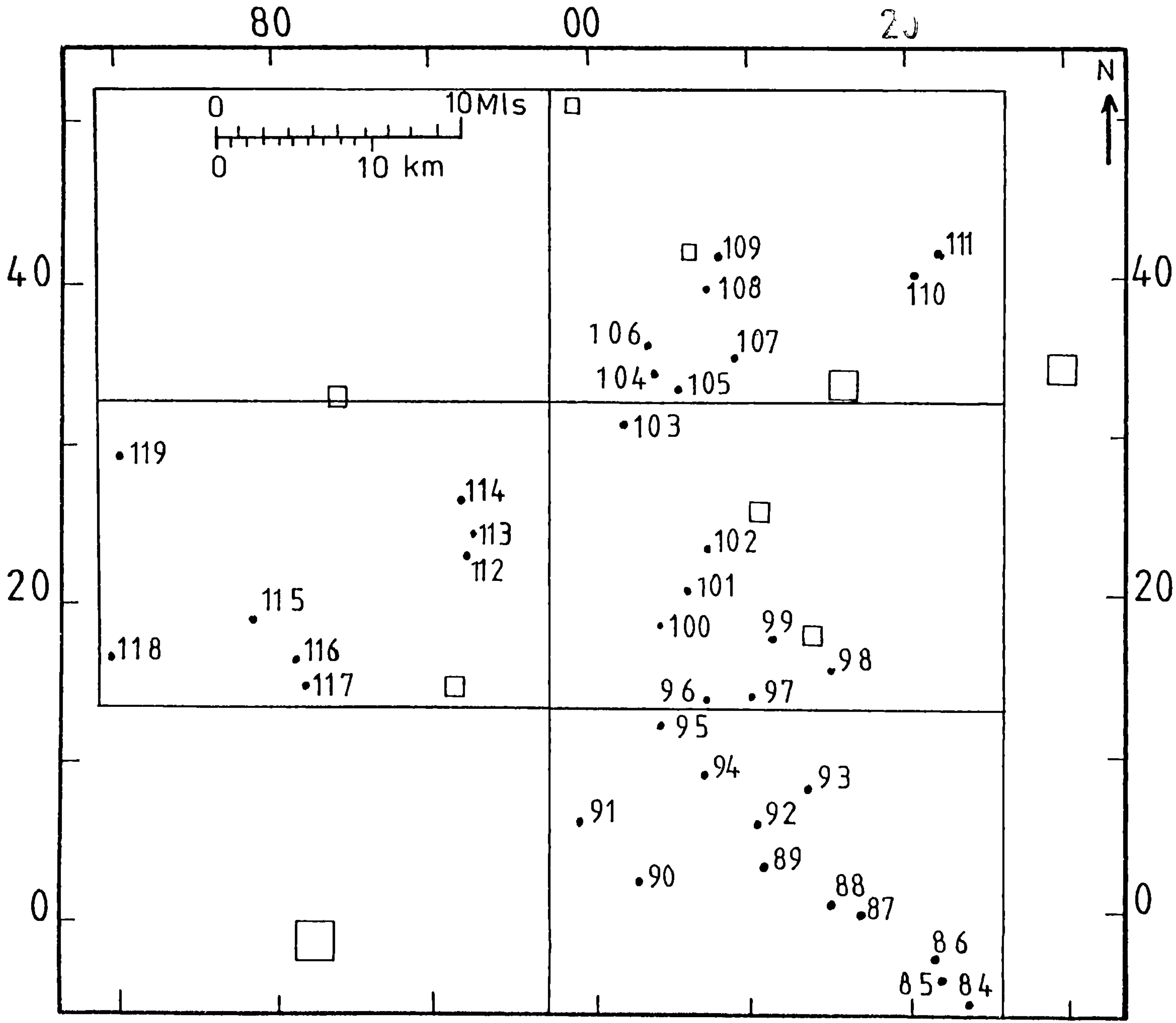
LEGEND

L	Late
T	Typical
E	Early
Tp	Type
Ta	aff gracile
Lc	cf Late
Ts	Gracile s.l.
+	Coexistence
{	Composite Band
....	uppermost band
....	middle band
....	lowermost band
→	Indicates Location
Me	Metabilingue
Ln	Lingula
G	Gastrioceras lineatum
S	Gastrioceras ? sigma
M	Undifferentiated marine fossils

Fig. 8B.

Base map of Figure 8 showing localities of occurrence of Bands of *R. bilingue* typical.

Numbered localities are listed in Tables 5A and 5B, pages 38 and 39.



80
00
2J
40
20
0
N
0
10Mls
0
10 km
119
114
113
112
115
118
116
117
109
108
111
110
106
107
104
105
103
102
101
100
99
98
96
97
95
94
93
91
92
89
90
88
87
86
85
84

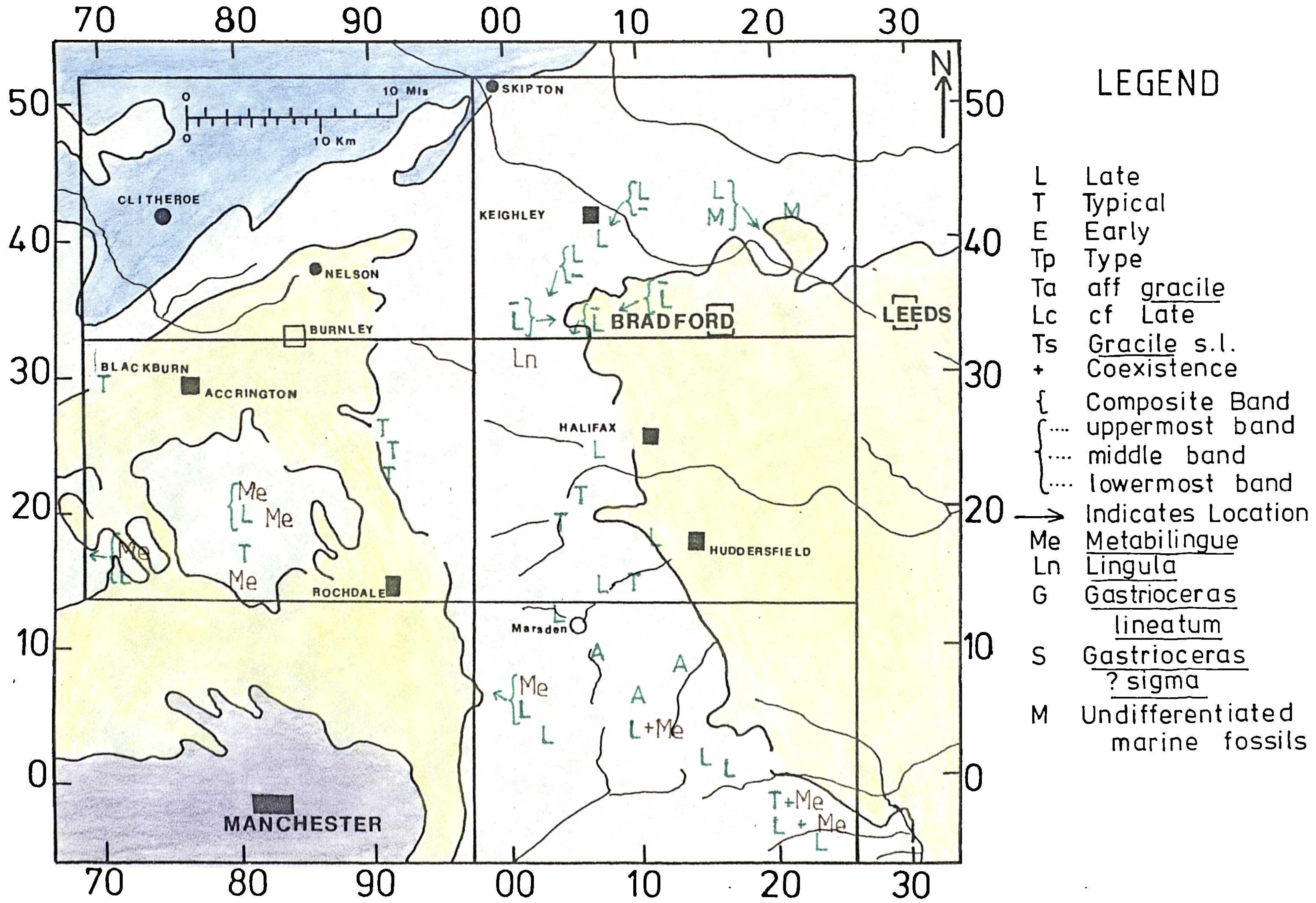
Fig. 9.

Occurrence and Distribution of band of *R. bilingue* late.

Yellow (West Parts) .... Burnley Coalfield (Westphalian).

Yellow (East Parts) .... West Yorkshire Coalfield (Westphalian).

Blue .... Mainly Limestone (Lower Carboniferous).

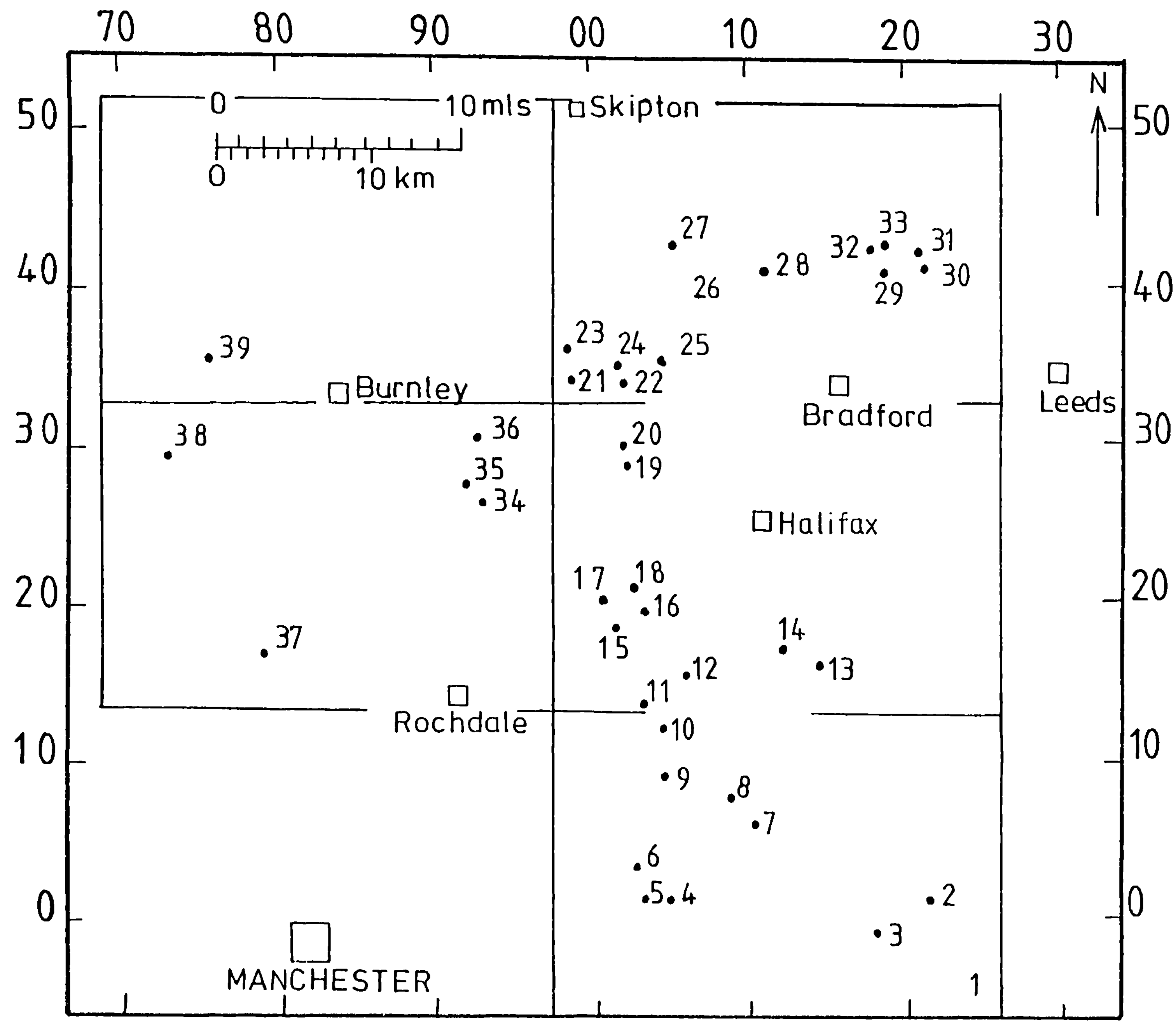


LEGEND
L Late
T Typical
E Early
Tp Type
Ta aff gracile
Lc cf Late
Ts Gracile s.l.
+ Coexistence
{ Composite Band
uppermost band
middle band
lowermost band
Indicates Location
Me Metabilingue
Ln Lingula
G Gastrioceras lineatum
S Gastrioceras ? sigma
M Undifferentiated marine fossils
CLITHEROE
NELSON
BURNLEY
BLACKBURN
ACCRINGTON
ROCHDALE
MANCHESTER
SKIPTON
KEIGHLEY
BRADFORD
LEEDS
HALIFAX
HUDDERSFIELD
Marsden
10 Mls
10 Km
N

Fig. 9B.

Base Map of Fig. 9 showing localities of occurrence of band of _R. bilingue_ late.

Numbered localities are listed in Tables 6A and 6B, pages 41 and 42.

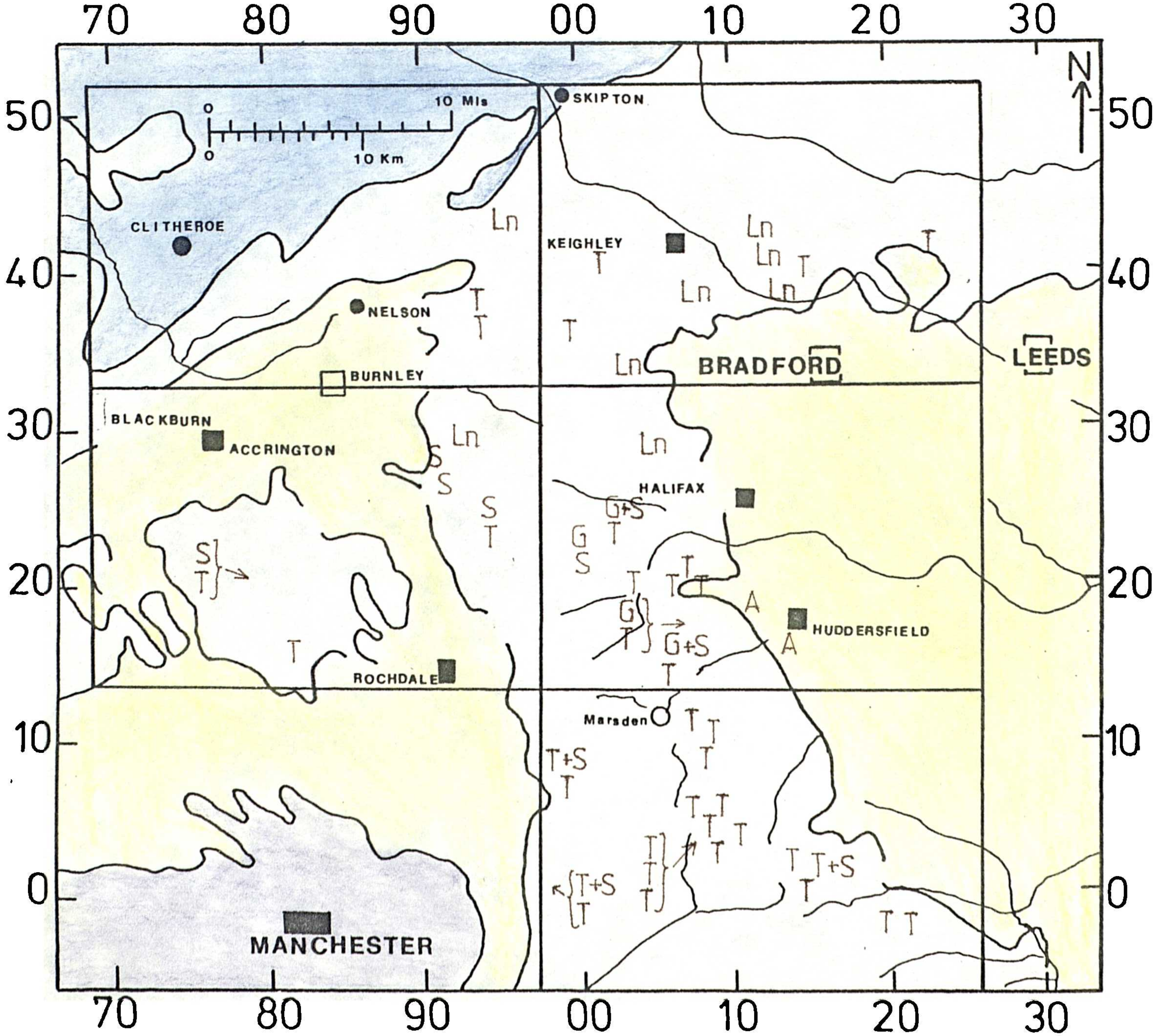


10 mls
10 km
N
Skipton
Burnley
Bradford
Leeds
Halifax
Rochdale
MANCHESTER

Fig. 10.

Occurrence and Distribution of band of _R. superbilingue_.

Yellow (West Parts)	....	Burnley Coalfield (Westphalian).
Yellow (East Parts)	....	West Yorkshire Coalfield (Westphalian).
Blue	....	Mainly Limestone (Lower Carboniferous).
Purple	....	Permo-Trias.



LEGEND

L	Late
T	Typical
E	Early
Tp	Type
Ta	aff gracile
Lc	cf Late
Ts	Gracile s.l.
+	Coexistence
{	Composite Band
{....	uppermost band
....	middle band
....	lowermost band
→	Indicates Location
Me	Metabilingue
Ln	Lingula
G	Gastrioceras lineatum
S	Gastrioceras ? sigma
M	Undifferentiated marine fossils

Fig. 10B.

Base Map of Figure 10 showing localities of occurrence of band of *R. superbilingue*.

Numbered localities are listed in Tables 8A and 8B, pages 46 and 47.

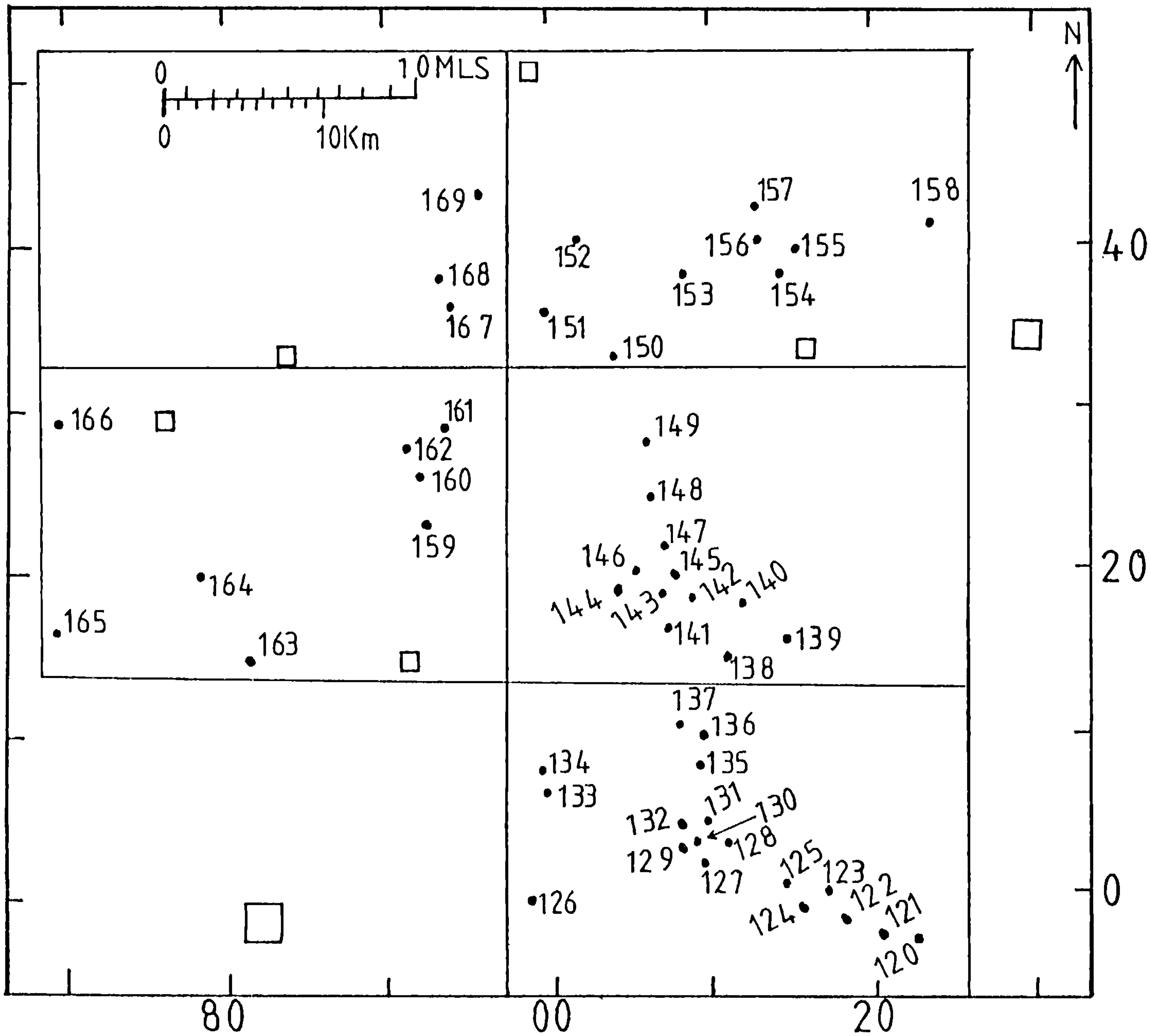
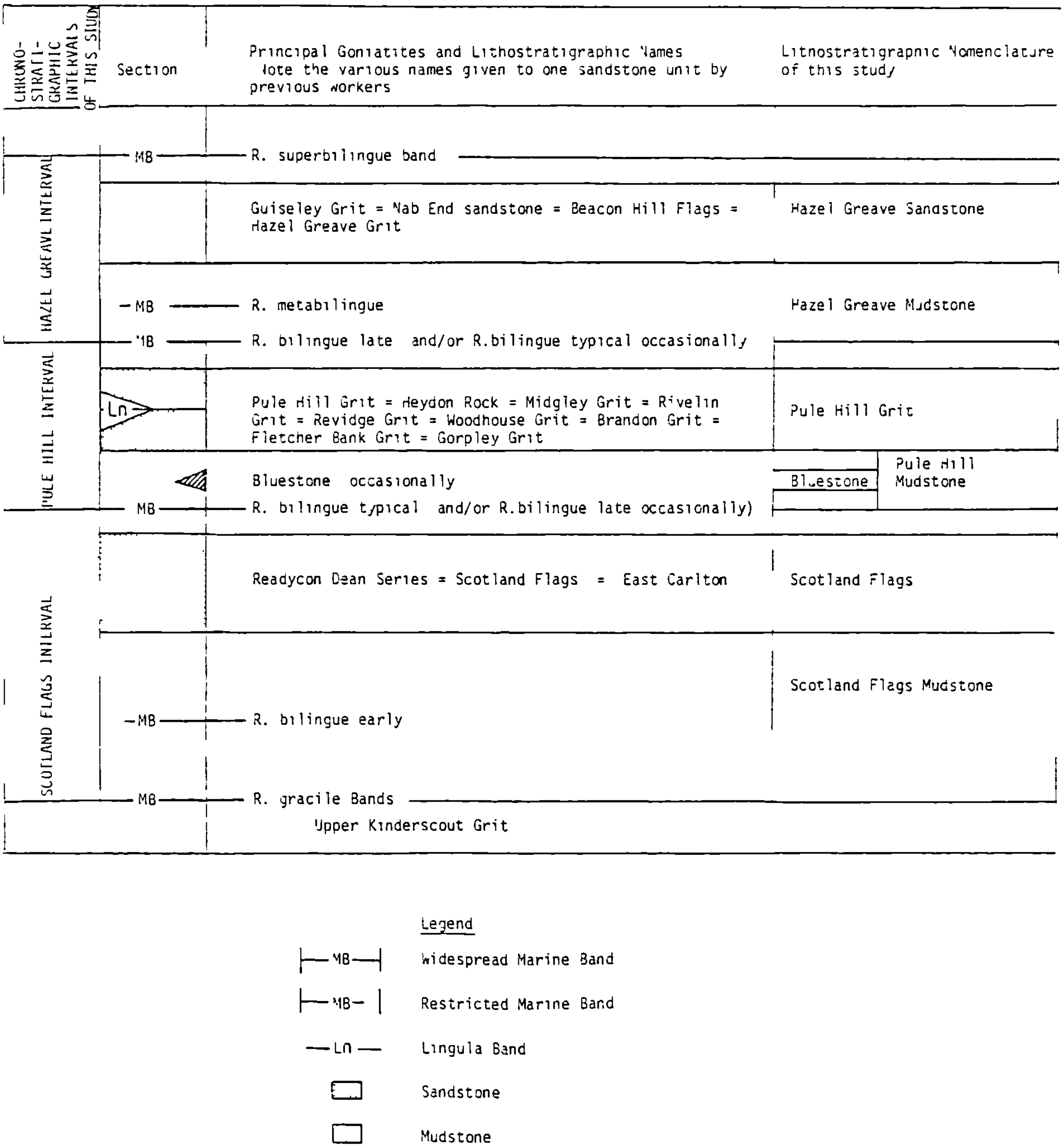

N
0
10MLS
0
10Km
169
168
167
166
161
162
160
159
164
165
163
157
158
152
156
155
153
154
151
150
149
148
147
146
145
144
143
142
140
141
139
138
137
136
134
135
133
132
131
130
129
128
127
125
123
126
124
122
121
120
40
20
0
80
00
20

Fig. 11. Generalized Section showing the Principal Goniatites and Lithostratigraphic Units in the Middle-Lower Marsdenian (Namurian P2AB) Stage.



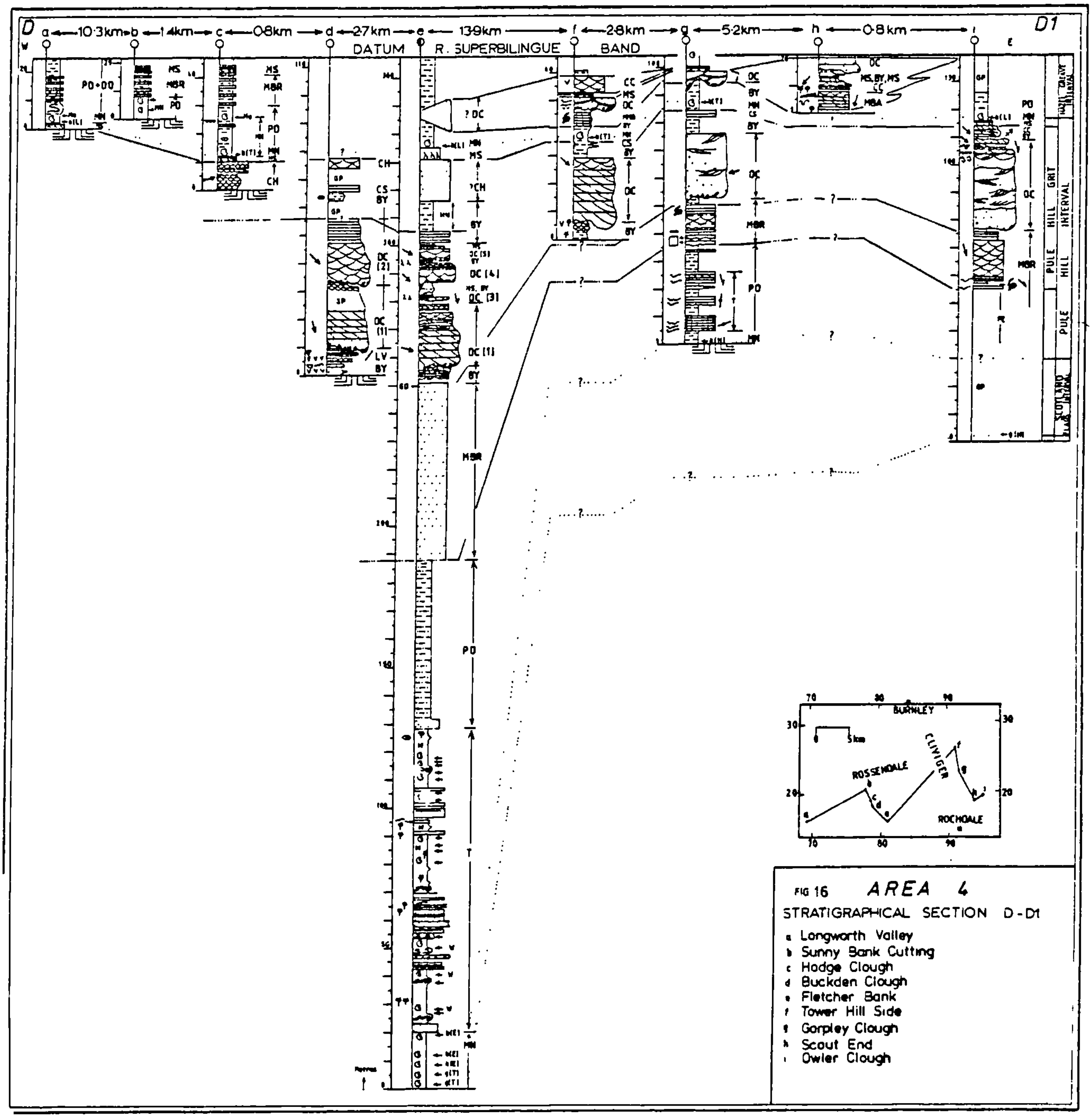


FIG 16 *AREA 4*

STRATIGRAPHICAL SECTION D-D1

- a Longworth Valley
- b Sunny Bank Cutting
- c Hodge Clough
- d Buckden Clough
- e Fletcher Bank
- f Tower Hill Side
- g Gorpley Clough
- h Scout End
- i Owler Clough

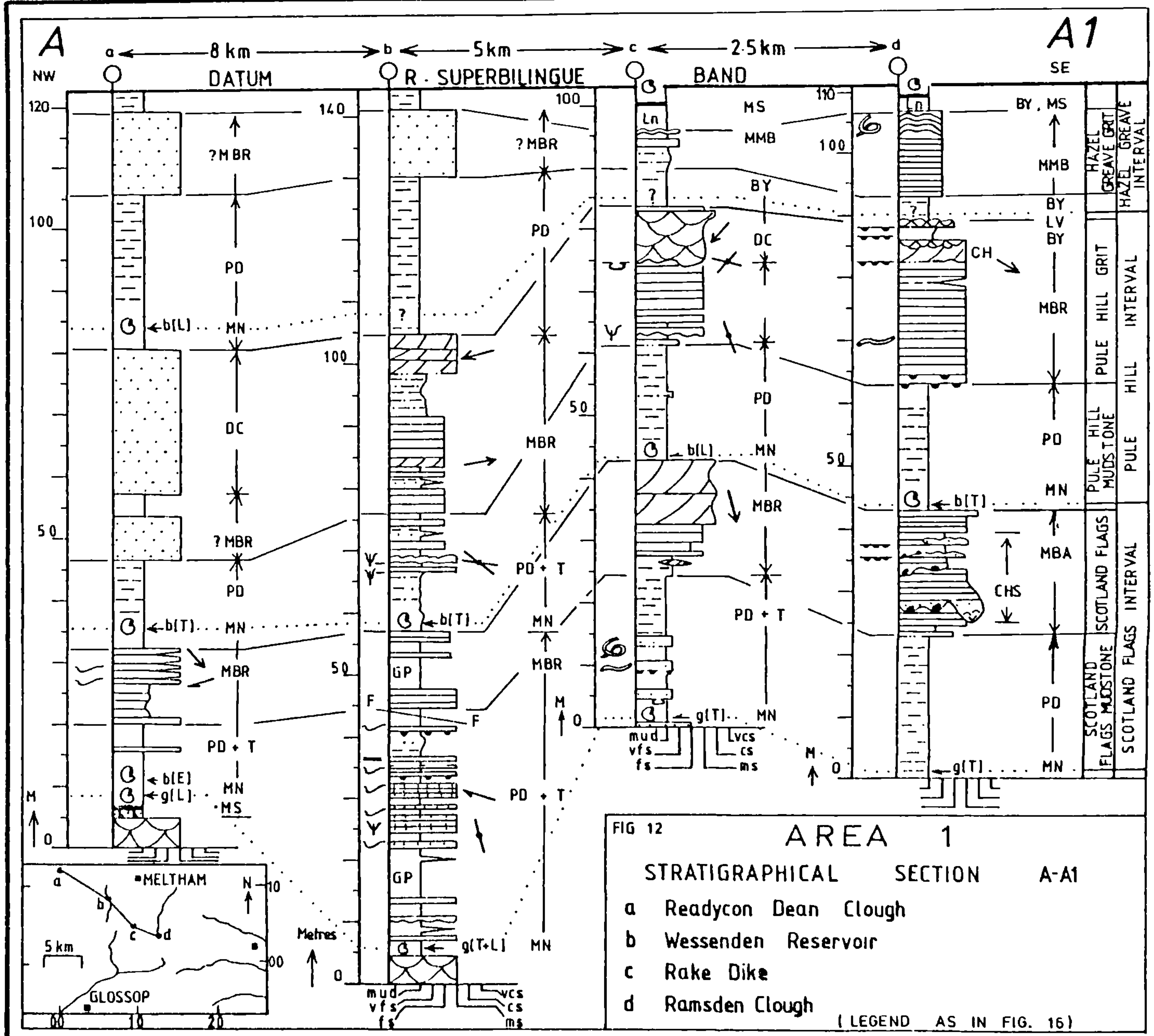


FIG 12

AREA 1

STRATIGRAPHICAL SECTION A-A1

a Readycon Dean Clough

b Wessenden Reservoir

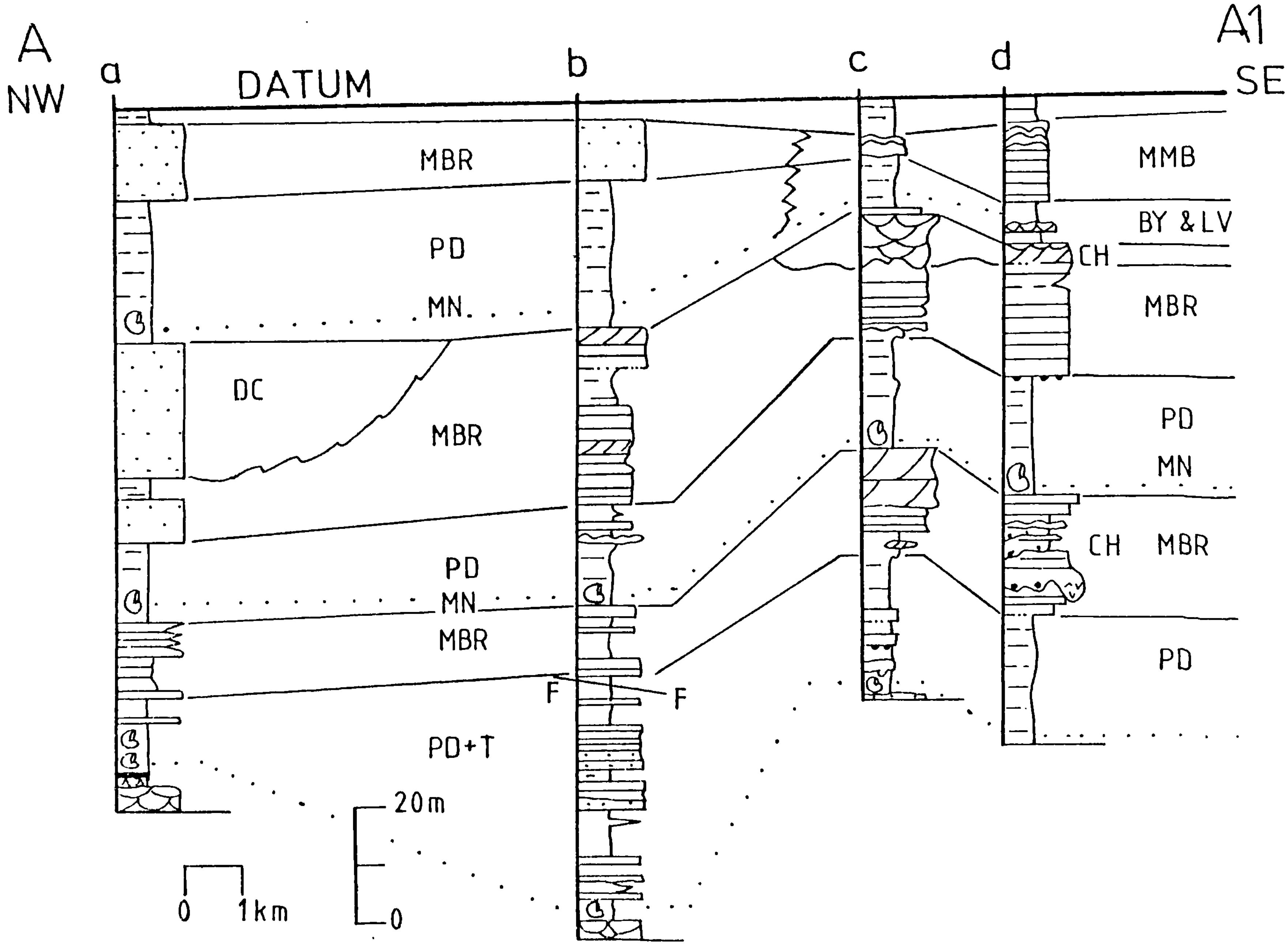
c Rake Dike

d Ramsden Clough

(LEGEND AS IN FIG. 16)

Fig. 12B.

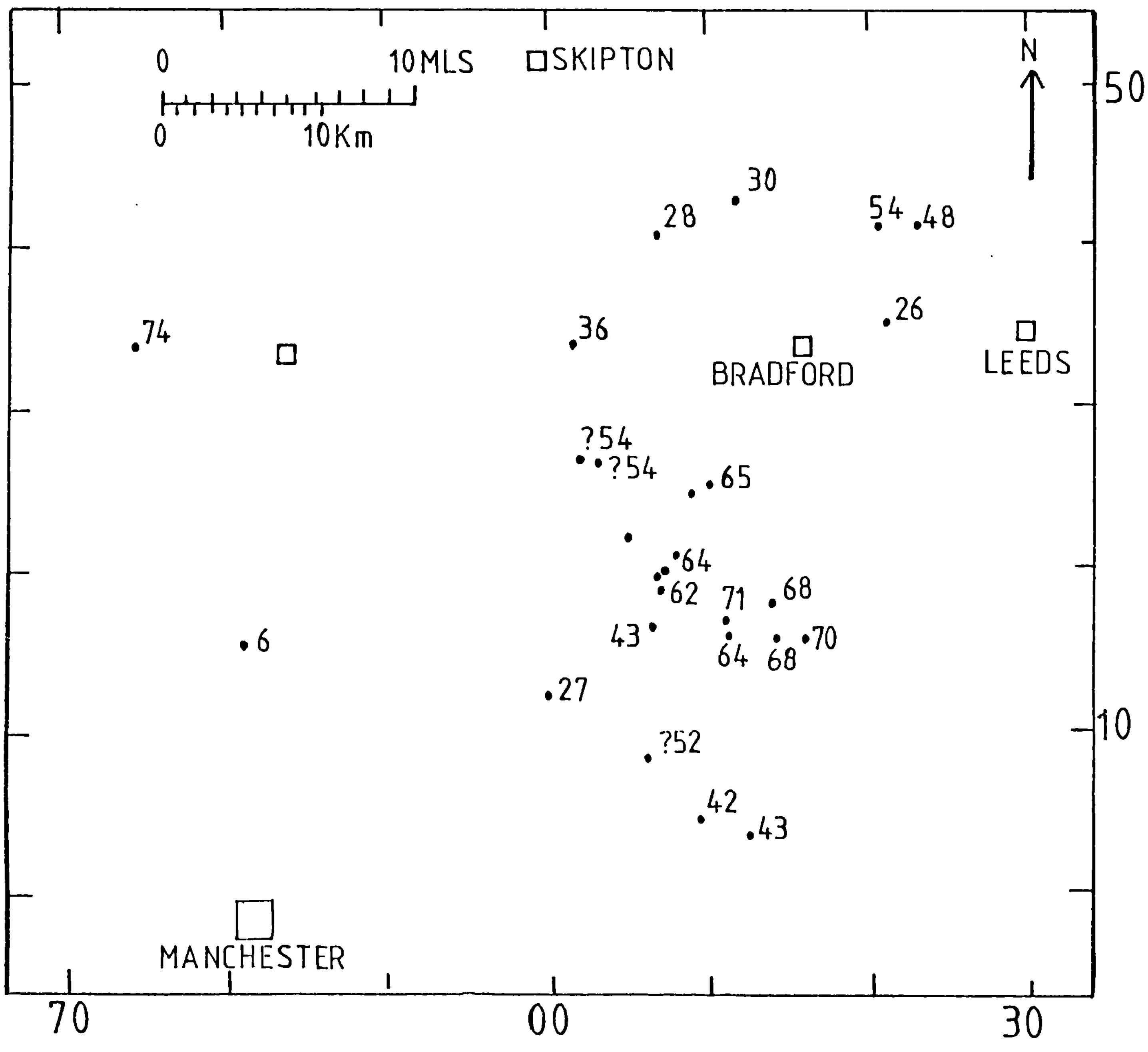
Stratigraphical Section A-A1 in area 1 showing the interpreted palaeoenvironments. The vertical sections in this figure are derived from Fig. 12. which should be referred to for fuller details. Datum is the same as in Fig. 12 (see the page facing Fig. 16 for legend).



A
NW
A1
SE
a
b
c
d
DATUM
MBR
PD
MN.
DC
MBR
PD
MN
MBR
F
F
PD+T
MMB
BY & LV
CH
MBR
PD
MN
CH
MBR
PD
20m
0
0
1km

Fig. 13.

Thickness distribution of Scotland Flags Interval. Scale in metres.


0
10MLS
0
10Km
SKIPTON
N
50
30
28
54
48
26
74
36
BRADFORD
LEEDS
?54
?54
65
64
62
71
68
6
43
64
68
70
27
10
?52
42
43
MANCHESTER
70
00
30

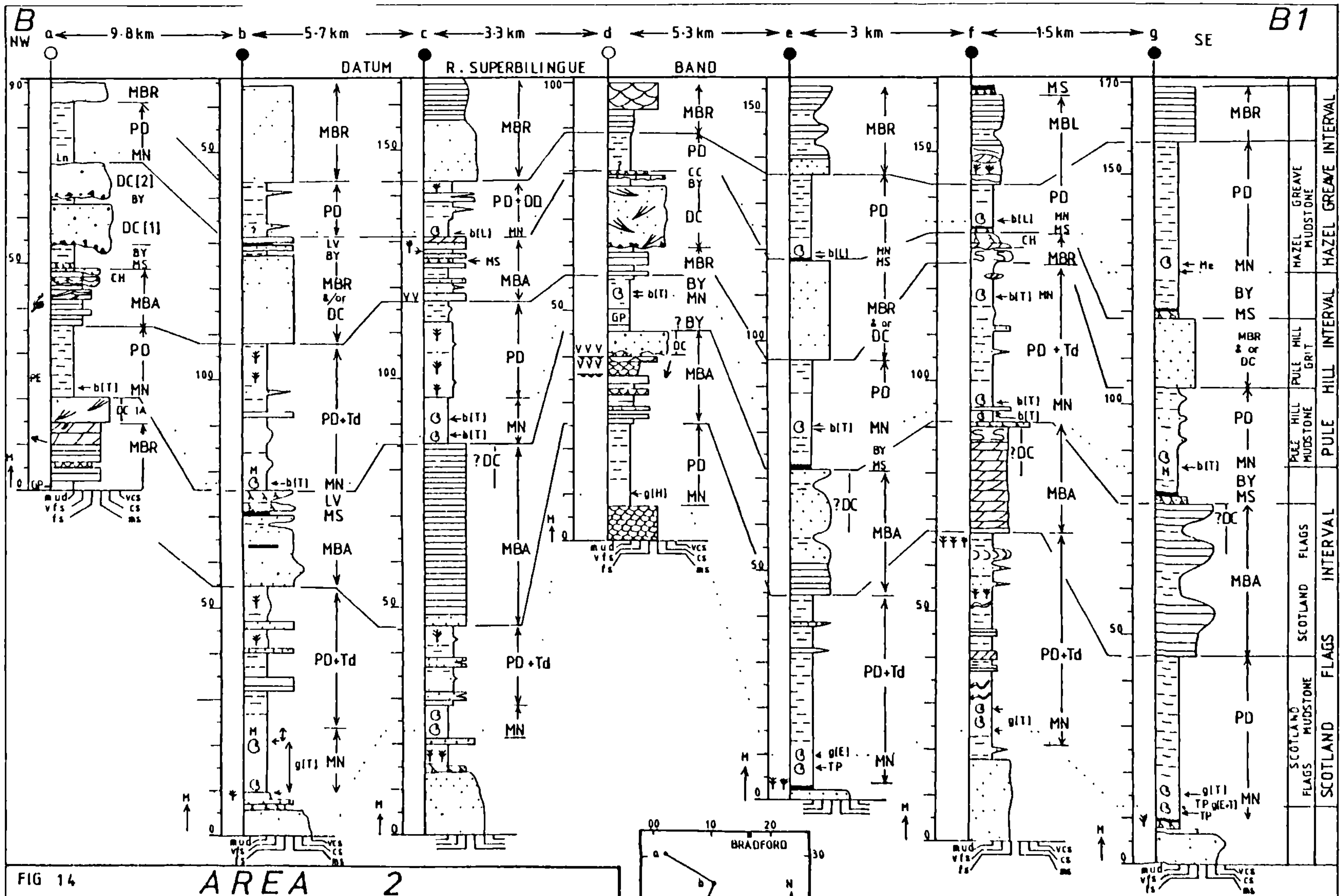


FIG 14 AREA 2

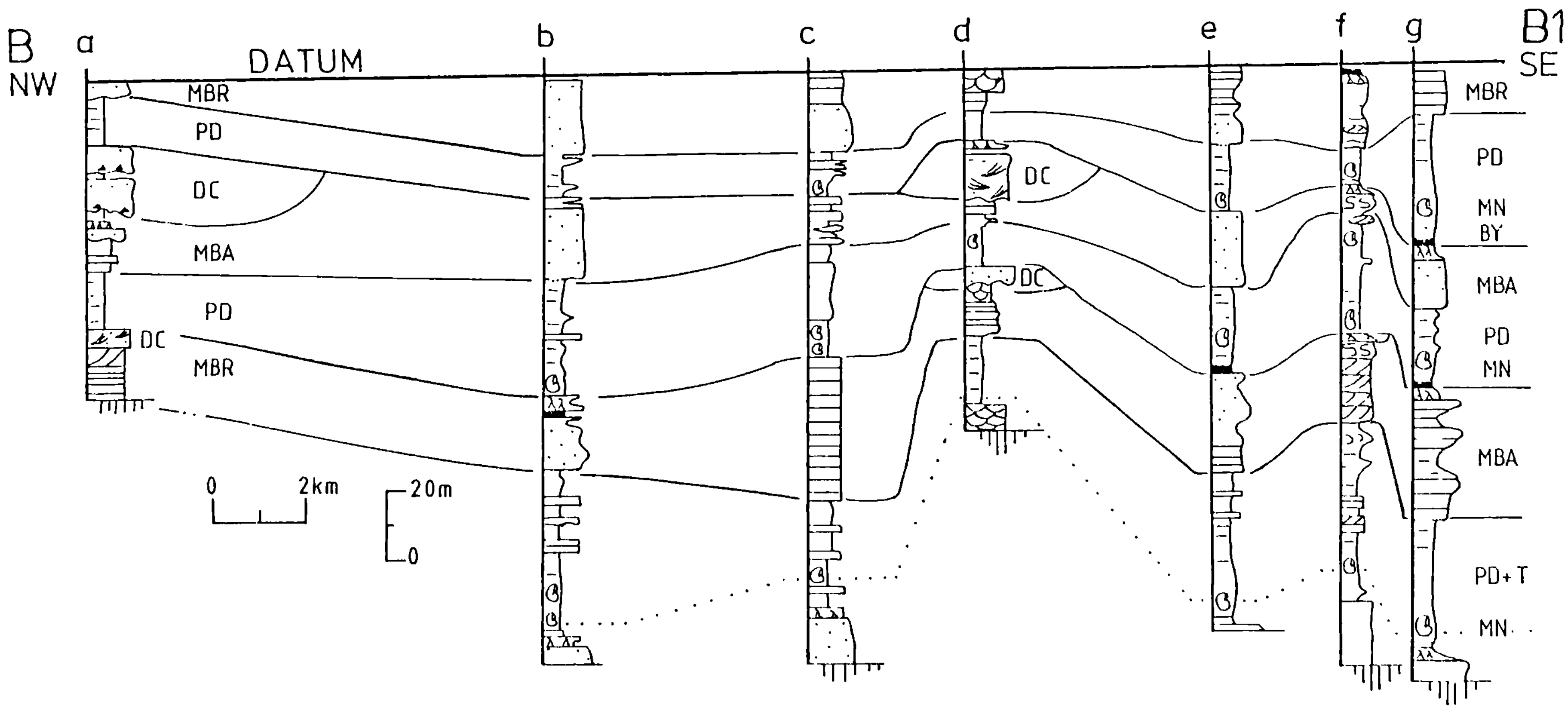
STRATIGRAPHICAL SECTION B - B1

a Bare Clough
b Patons & Boldwins Borehole
c Bower's Mill Borehole No 1
d Red Lane Dike
e Quarmby Clough Mill Borehole
f Colne Road Mills No.1 Borehole
g Mold Green Borehole

(LEGEND AS IN FIG 16)

Fig. 14B

Stratigraphical section B-B1 in area 2 showing the interpreted palaeoenvironments. The vertical sections in this figure are derived from Fig. 14 which should be referred to for fuller details. Datum is the same as in Fig. 14 (see the page facing Fig. 16 for legend).


B
NW
a
b
c
d
e
f
g
B1
SE
DATUM
MBR
PD
DC
MBA
PD
DC
MBR
DC
DC
MN
BY
MBA
PD
MN
MBA
PD+T
MN
0
2km
20m
0

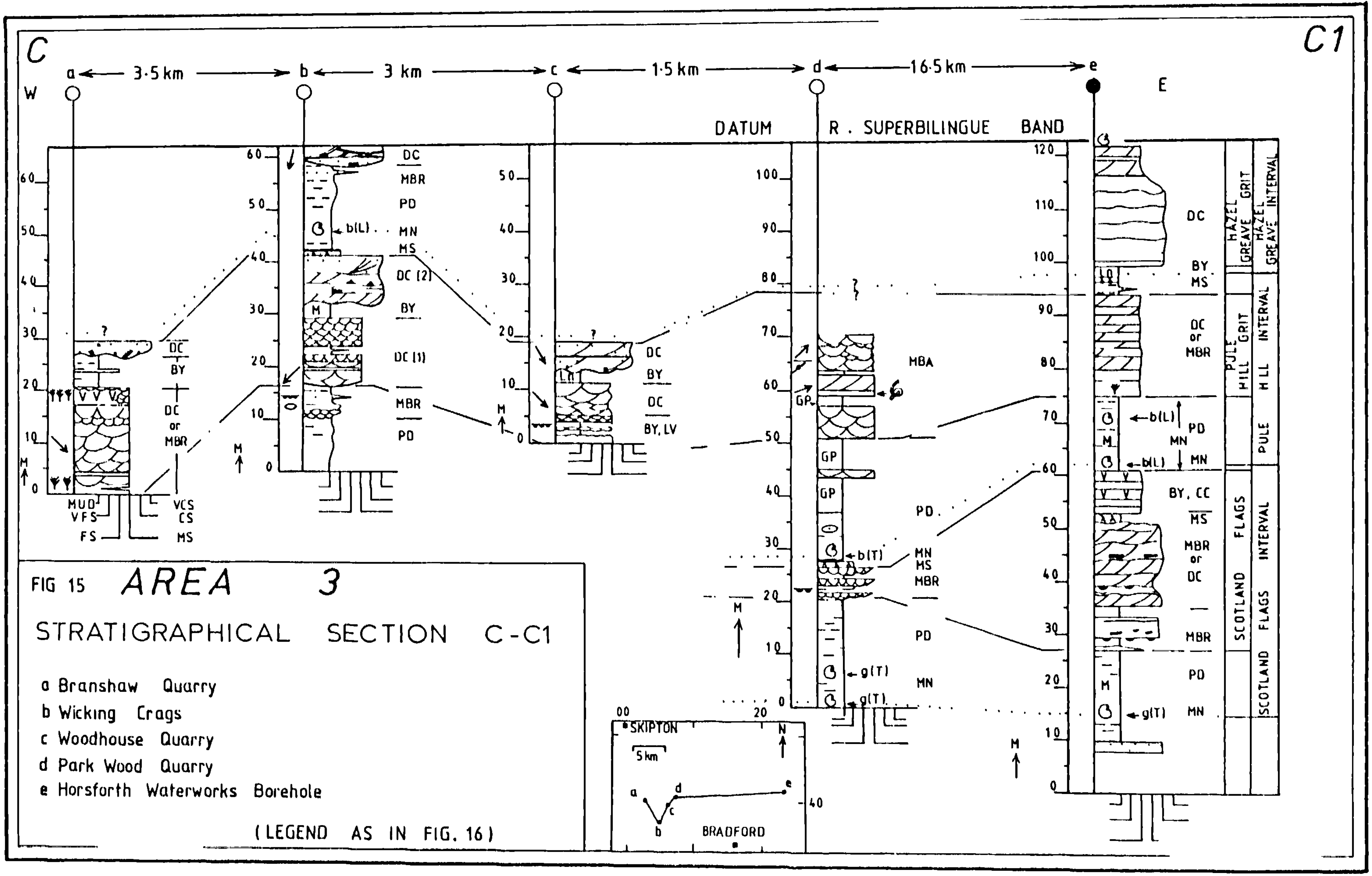


FIG 15 *AREA* 3

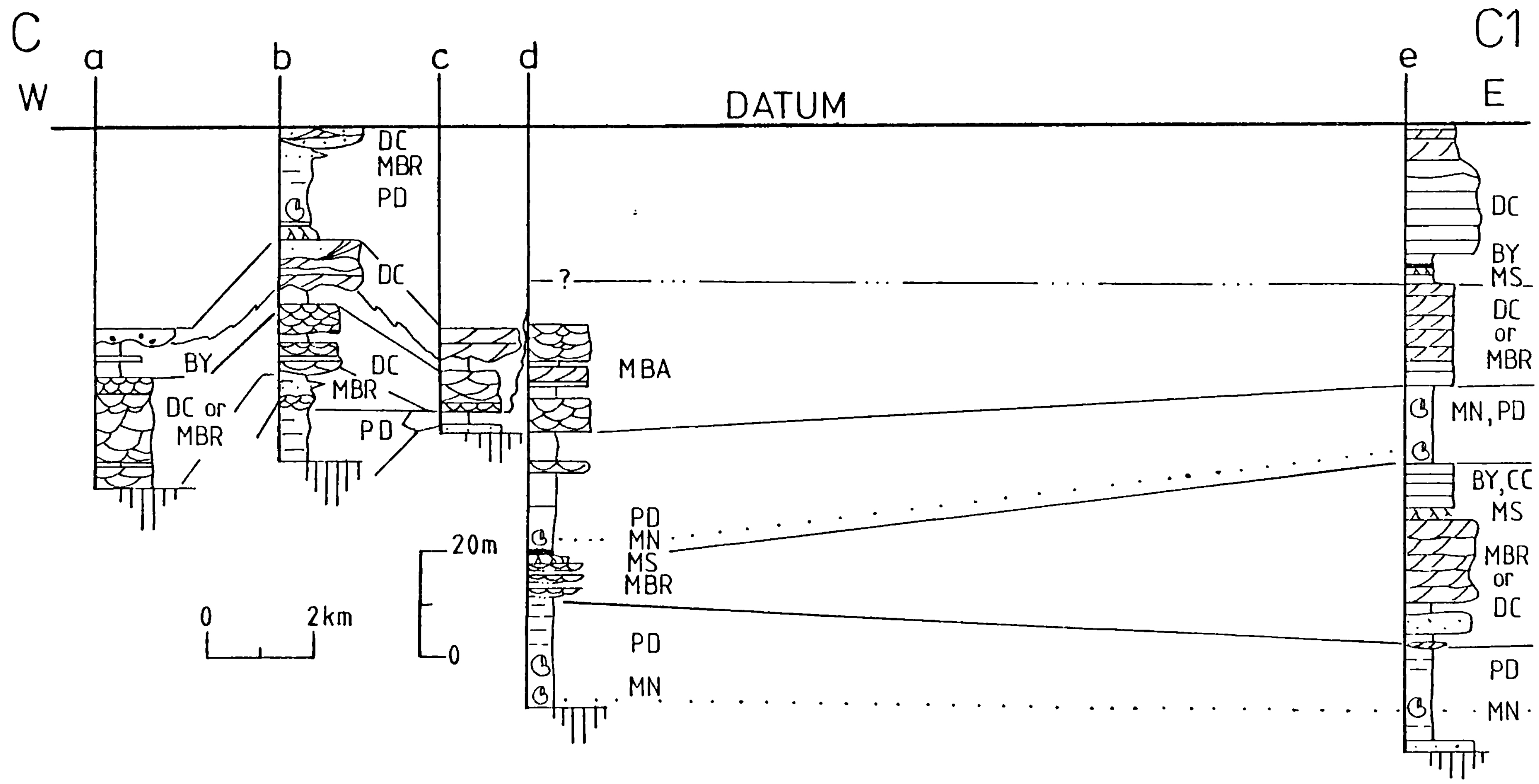
STRATIGRAPHICAL SECTION C-C1

a Branshaw Quarry
b Wicking Crags
c Woodhouse Quarry
d Park Wood Quarry
e Horsforth Waterworks Borehole

(LEGEND AS IN FIG. 16)

Fig. 15B.

Stratigraphical section C-C1 in area 3 showing the interpreted palaeoenvironments. The vertical sections in this figure are derived from Fig. 15 which should be referred to for fuller details. Datum is the same as in Fig. 15 (see the page facing Fig. 16 for legend).


C
W
a
b
c
d
DATUM
e
C1
E
DC
MBR
PD
DC
BY
DC or
MBR
DC
MBR
PD
?
MBA
PD
MN
MS
MBR
PD
MN
20m
0
0
2km
DC
BY
MS
DC
or
MBR
MN, PD
BY, CC
MS
MBR
or
DC
PD
MN

LEGEND - STRATIGRAPHIC SECTIONS "A-A1" TO "E-E1" & OTHER VERTICAL SECTIONS

Abbreviations

Marine	MN
Prodelta	PD
Turbidite	-
Distal Turbidite	Td
Density Current Deposits	DD
Mouth Bar	MBF
Mouth Bar Lateral Margin	MBL
Mouth Bar Area	MBA
Minor Mouth Bar	MMB
Bay	BY
Distributary Channel	DC
Crevasse Channel	CC
Crevasse Splay	CS
Levee	LV
Marsh	MS
R. ret. type form	TP
R. gracile	g
R. gracile (early)	g(E)
R. gracile (typical)	g(T)
R. gracile (late)	g(L)
R. gracile (horizon)	g(H)
R. bilingue (early)	b(E)
R. bilingue (typical)	b(T)
R. bilingue (late)	b(L)
R. Metabilingue	Me
R. wrighti	W
R. Superbilingue	R.Sup
Lingula band	Ln
Poor Exposure	PE
Ground level	GD
Gap	GP
Questionable	?
UPPER Underscout horizon	UK(H)
Holcombe Brook	HB
Poor Exposure	PE
Swamp	SW
Non Goniatite Marine-Band	M
Horizontal arrow at right of vertical section point to specific goniatite location	
Plate	P

M written left of vertical section denotes metres.

Structures, Fossils; Others

Overturned beds

Slump

Trough Cross beds

Tabular Cross beds

Coal (Coal thickness exaggerated in Figs.)

Horizontally Stratified

Seatearth

Nodule

Gradational Contact

Conjectural Contact or

Sharp Contact

Sharp Contact Irregular

Interval Contact

Pelecypodichnus (Escape Shaft)

Pelecypodichnus hypichnal Ridge)+

Wood+

Plant+

Palaeophycus

Planolites

Olivellites

Surface Section

Subsurface Section

Subsurface & Surface Section

Palaeocurrent direction

Pelecypodichnus orientation

Ripple Flow direction

Plant Orientation

Scour Marks (direction known)

Scour Marks (direction unknown)

Dip direction of set boundary

Trough Cross Lamination

Flute

Load

Prod

Other Scours

Goniatite

Conglomerate

Breccia

Leaf Impression+

Mud Clast

Arthrophycus

Scour based sand body

Trough Cross Bed (poorly stratified)

Parallel Bedded or

Stratification destroyed by Pelecypodichnus

Massive

Dip and strike of bed

Tree Trunk in Growth Position

Zoophycos

Arenicolites

Dip Direction of Bed

Deformed Bed

Mudclast Orientation

0-25%	One Symbol	+
25-50%	Two Symbols	
> 50%	Three Symbols	

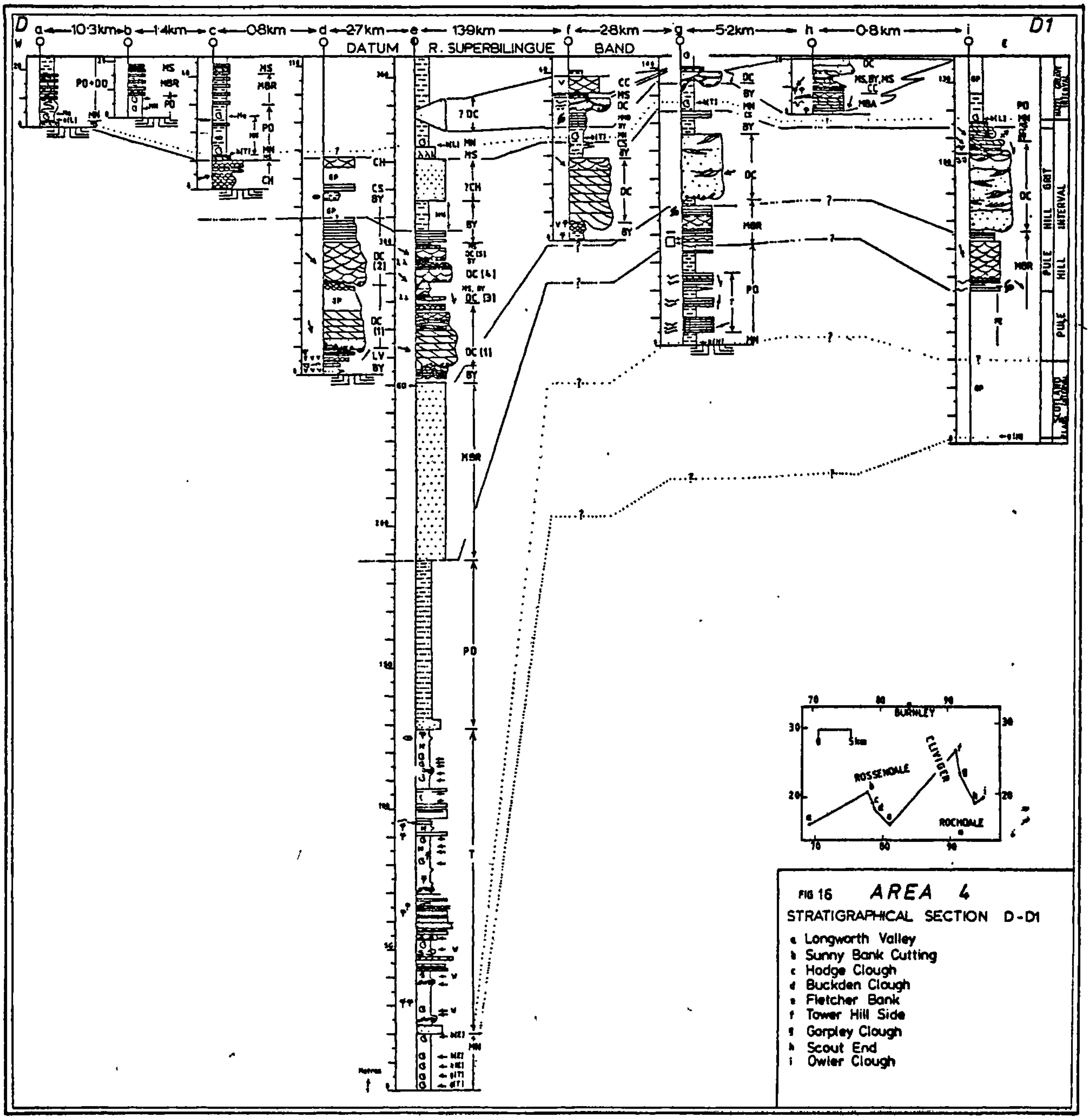


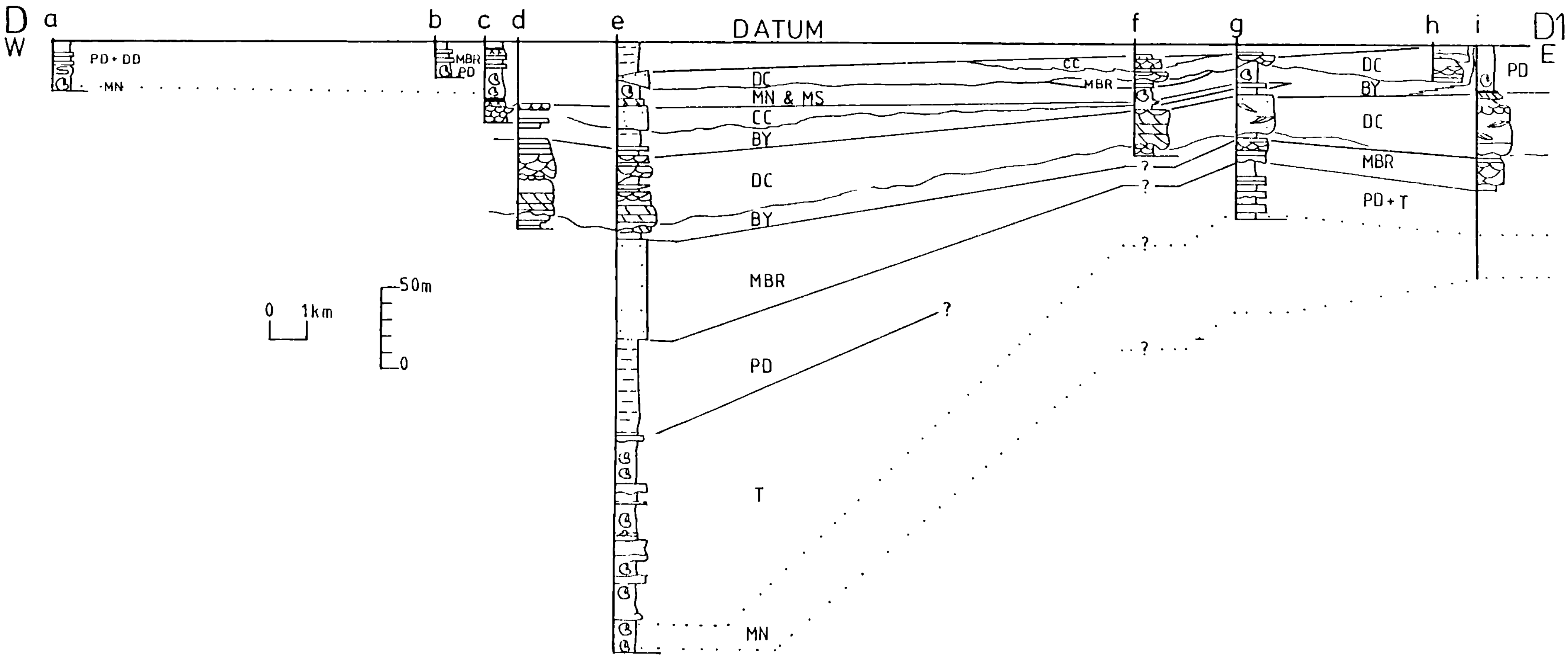
FIG 16 *AREA 4*

STRATIGRAPHICAL SECTION D-D1

- a Longworth Valley
- b Sunny Bank Cutting
- c Hodge Clough
- d Buckden Clough
- e Fletcher Bank
- f Tower Hill Side
- g Gorpley Clough
- h Scout End
- i Owler Clough

Fig. 16B

Stratigraphical section D-D1 in area 4 showing the interpreted palaeoenvironments. The vertical sections in this figure are derived from Fig. 16 which should be referred to for fuller details. Datum is the same as in Fig. 16 (see the page facing Fig. 16 for legend).



D
W
a
b
c
d
e
DATUM
f
g
h
i
D1
E
PD + DD
MN
MBR
PD
DC
MN & MS
CC
BY
DC
BY
MBR
PD
T
MN
CC
MBR
DC
BY
DC
MBR
PD + T
PD
?
0
1km
50m
0

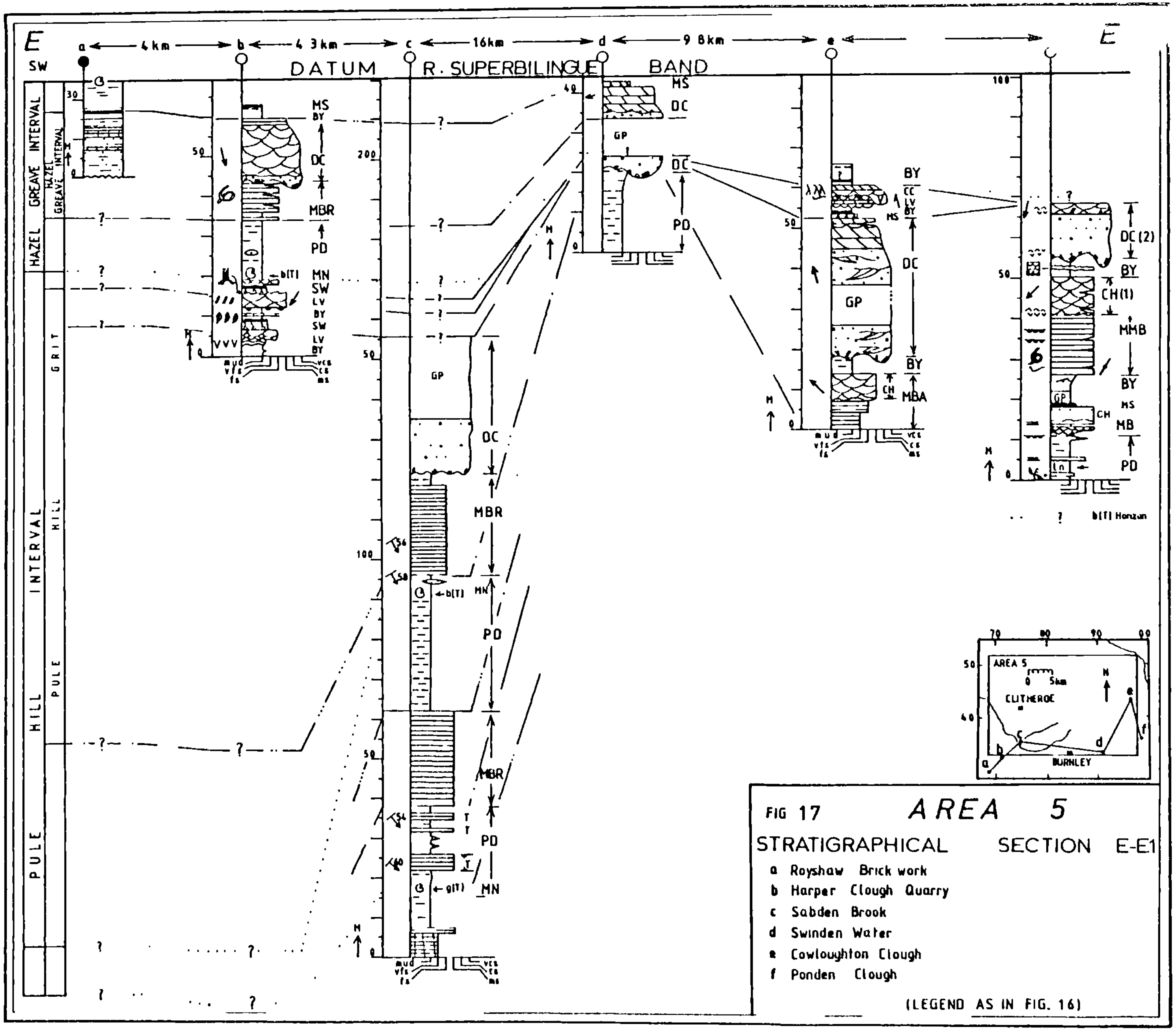


FIG 17 AREA 5

STRATIGRAPHICAL SECTION E-E1

- a Royshaw Brick work
- b Harper Clough Quarry
- c Sabden Brook
- d Swinden Water
- e Cowloughton Clough
- f Ponden Clough

(LEGEND AS IN FIG. 16)

Fig. 17B.

Stratigraphical section E-E1 in area 5 showing the interpreted palaeoenvironments. The vertical sections in this figure are derived from Fig. 17 which should be referred to for fuller details. Datum is the same as in Fig. 17 (see the page facing Fig. 17 for legend).

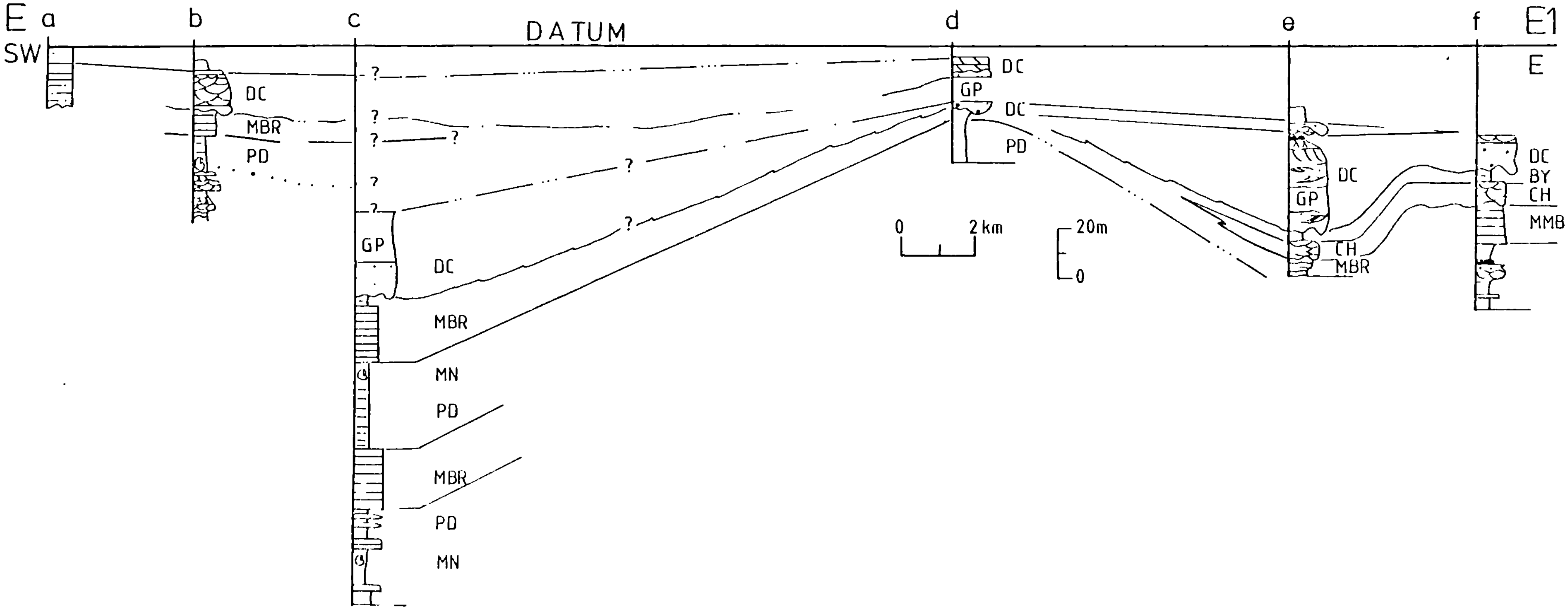

E
SW
a
b
c
DATUM
d
e
f
E1
E
DC
MBR
PD
GP
MN
CH
BY
MMB
0
2 km
20m
0

Fig. 18.

Thickness distribution of Scotland Flags. Scale in metres.

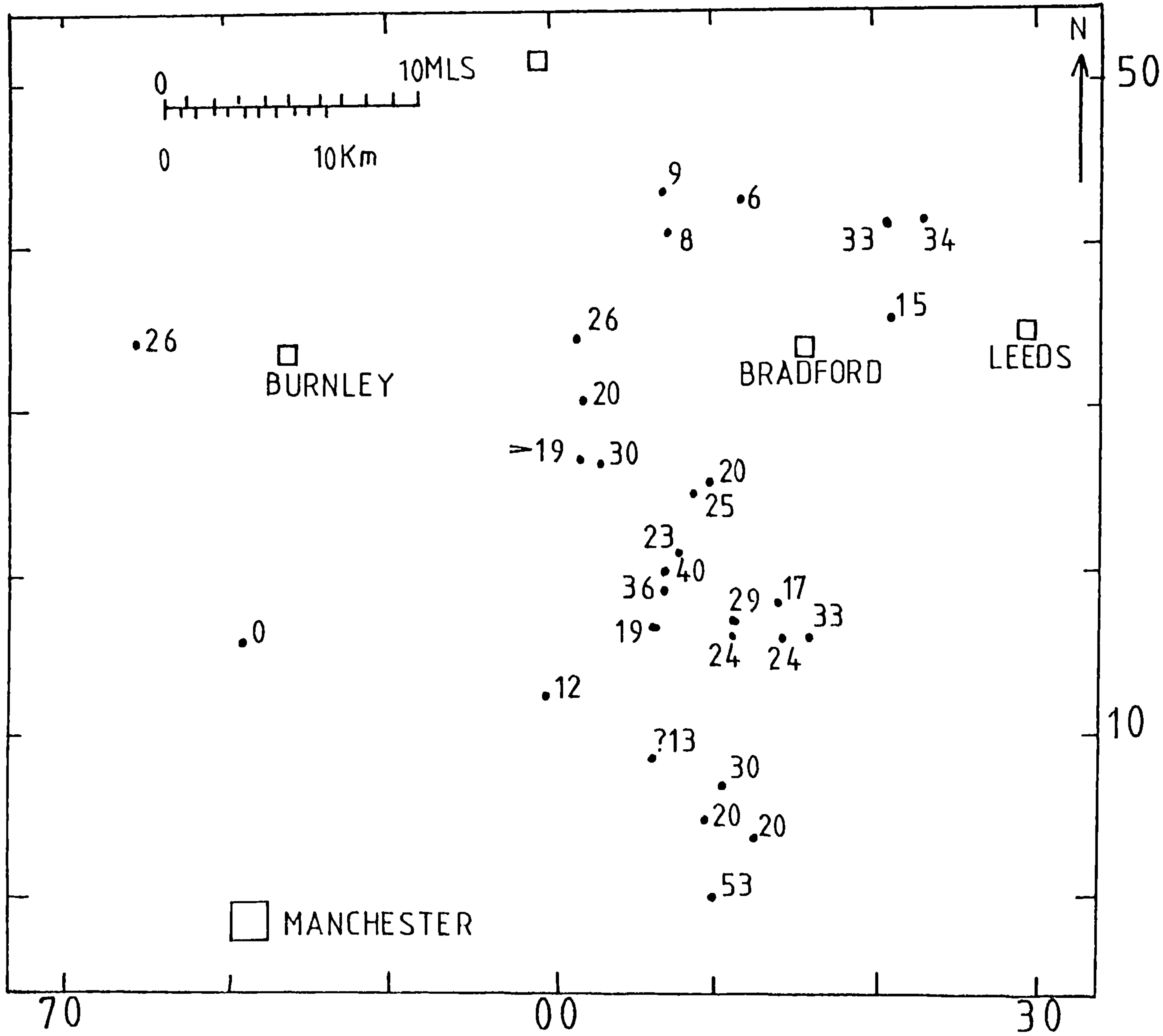
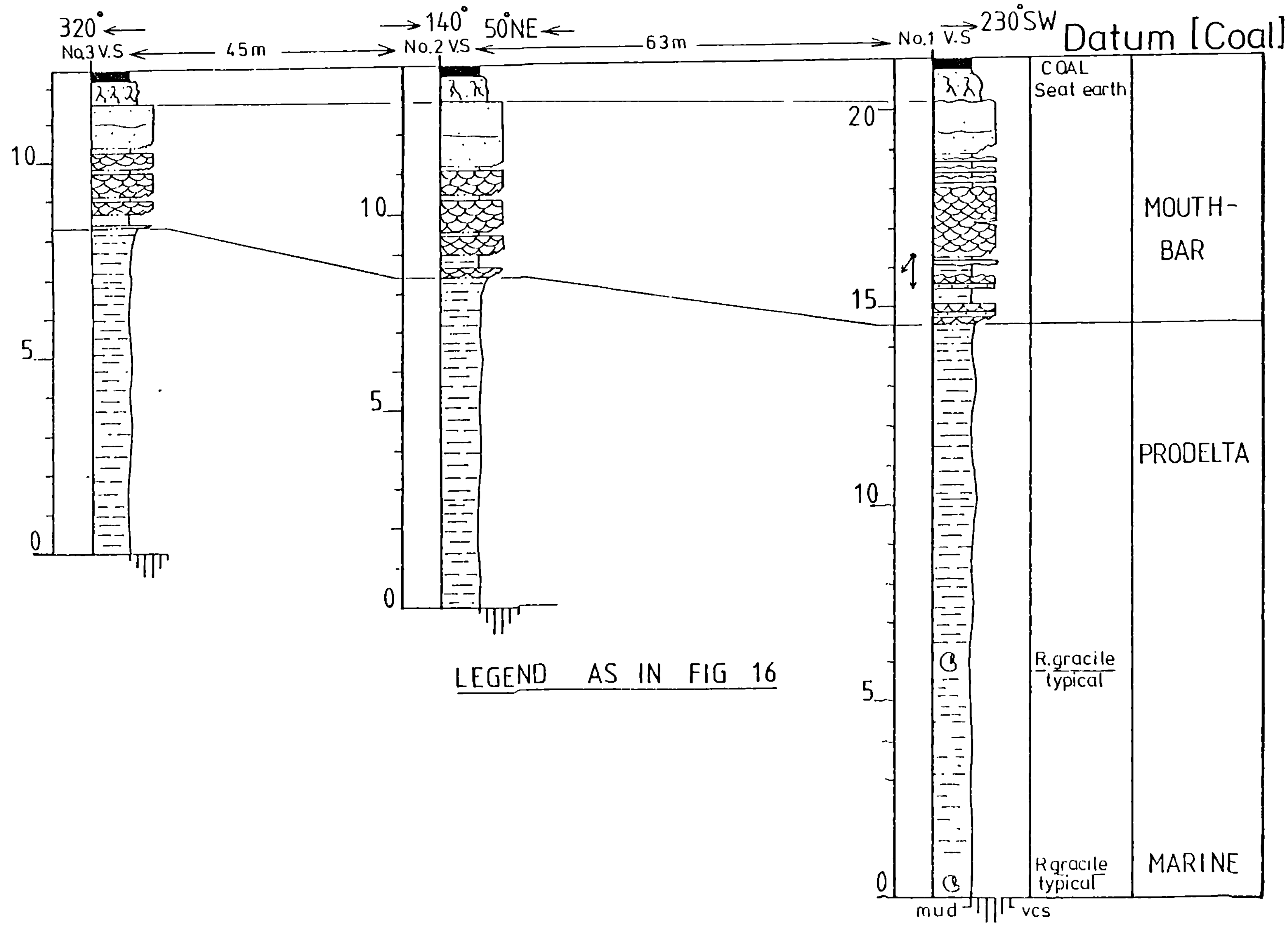

N
50
10
70
00
30
0
10MLS
0
10Km
LEEDS
BRADFORD
BURNLEY
MANCHESTER
9
6
8
33
34
15
26
26
20
>19
30
20
25
23
40
36
29
17
33
19
24
24
0
12
?13
30
20
20
53

Fig. 19.

NW-SE Stratigraphical section of the Scotland Flags Interval in Park Wood Quarry No. 1.

Fig. 19 occurs in level 0-28m of 'd' sequence in Fig. 15 (SE 066407).



LEGEND AS IN FIG 16

Fig. 20.

Detailed vertical section of the Upper Kinderscout Grit and the Scotland Flags Interval in Rag Clough (SE 014338).

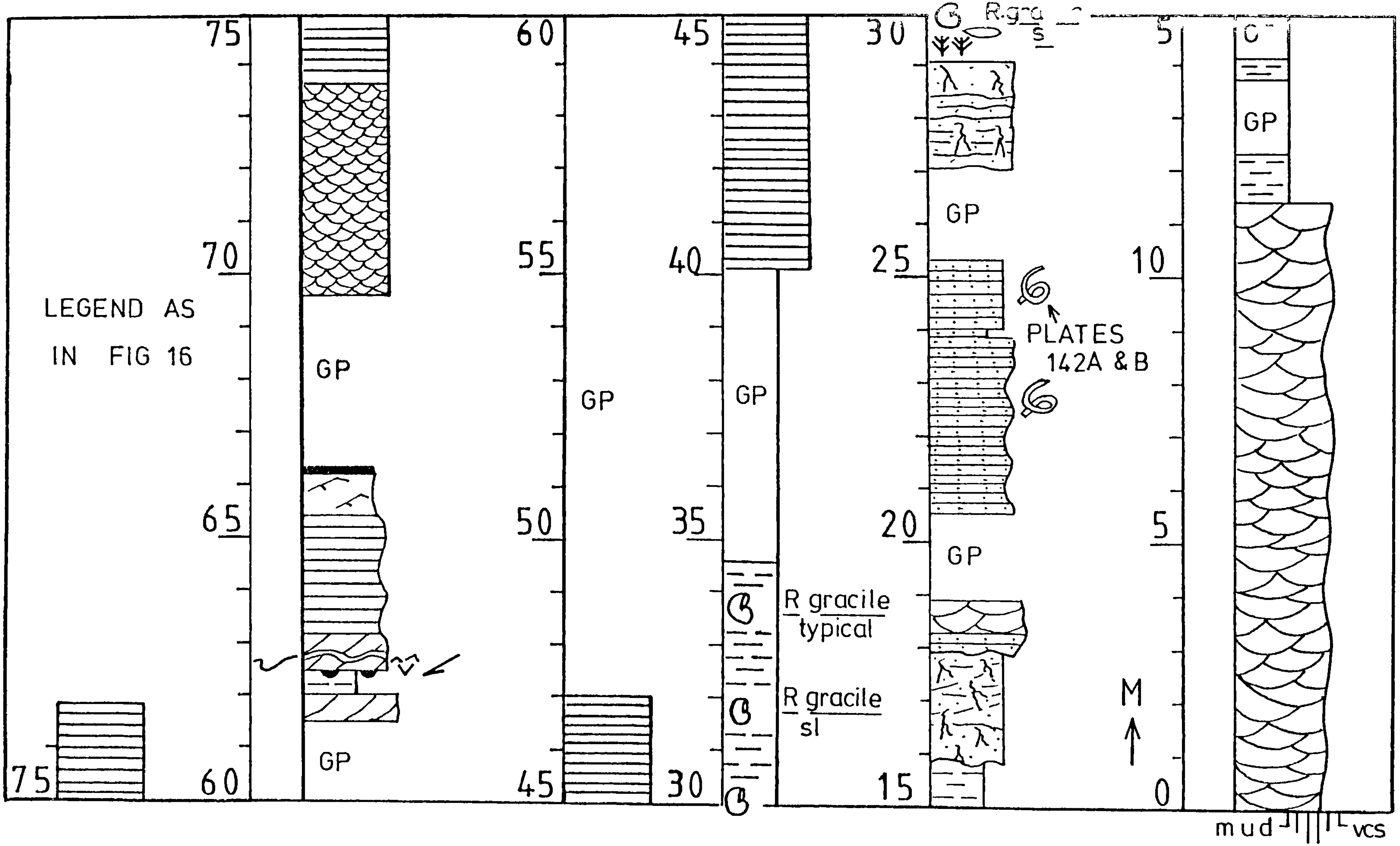

LEGEND AS IN FIG 16
75
70
65
60
GP
55
50
45
40
35
30
R gracile typical
R gracile sl
25
20
15
R.gra s
PLATES 142A & B
M
10
5
0
mud
vcs

Fig. 21.

Thickness distribution of Pule Hill Interval. Scale in metres.

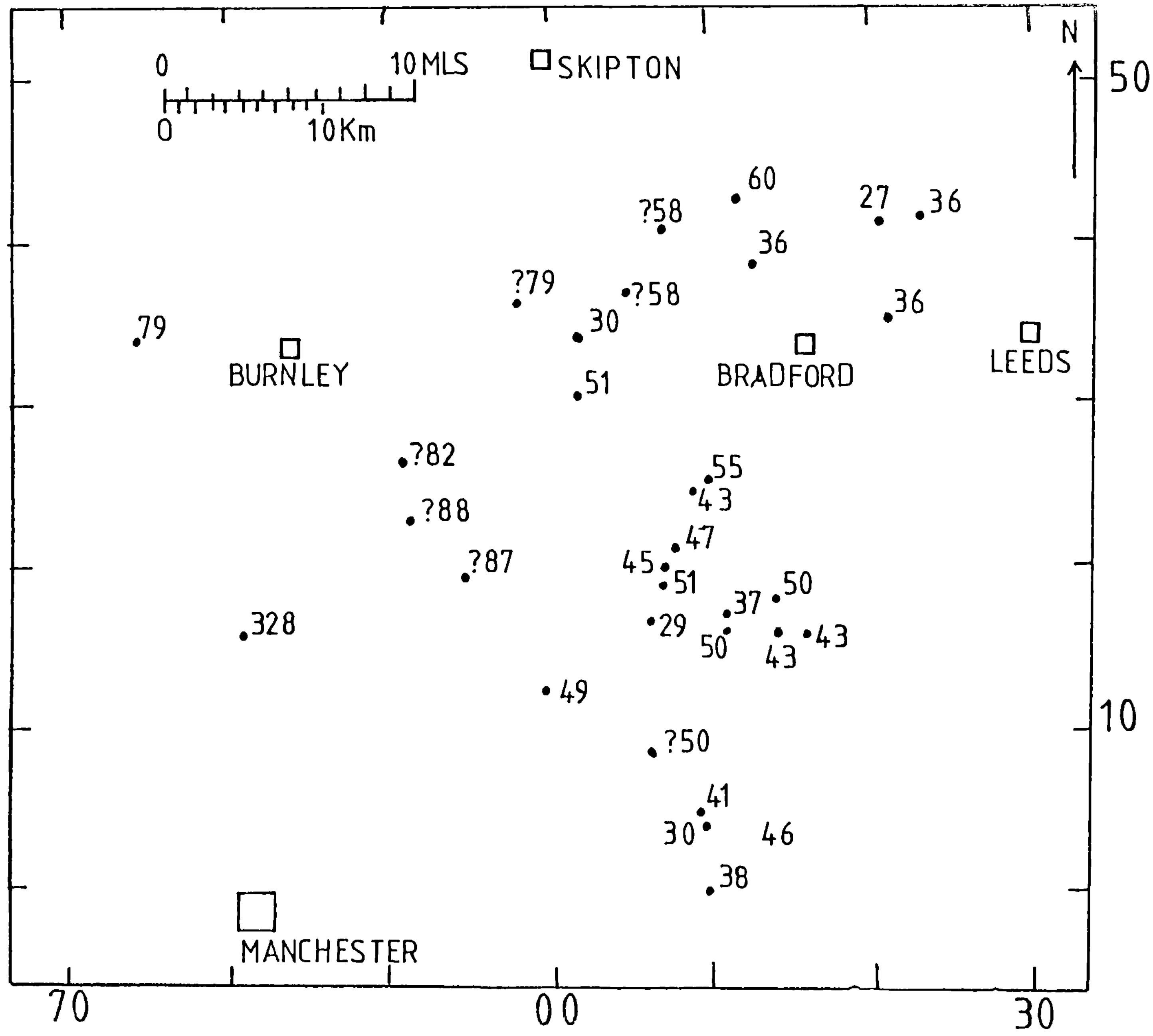
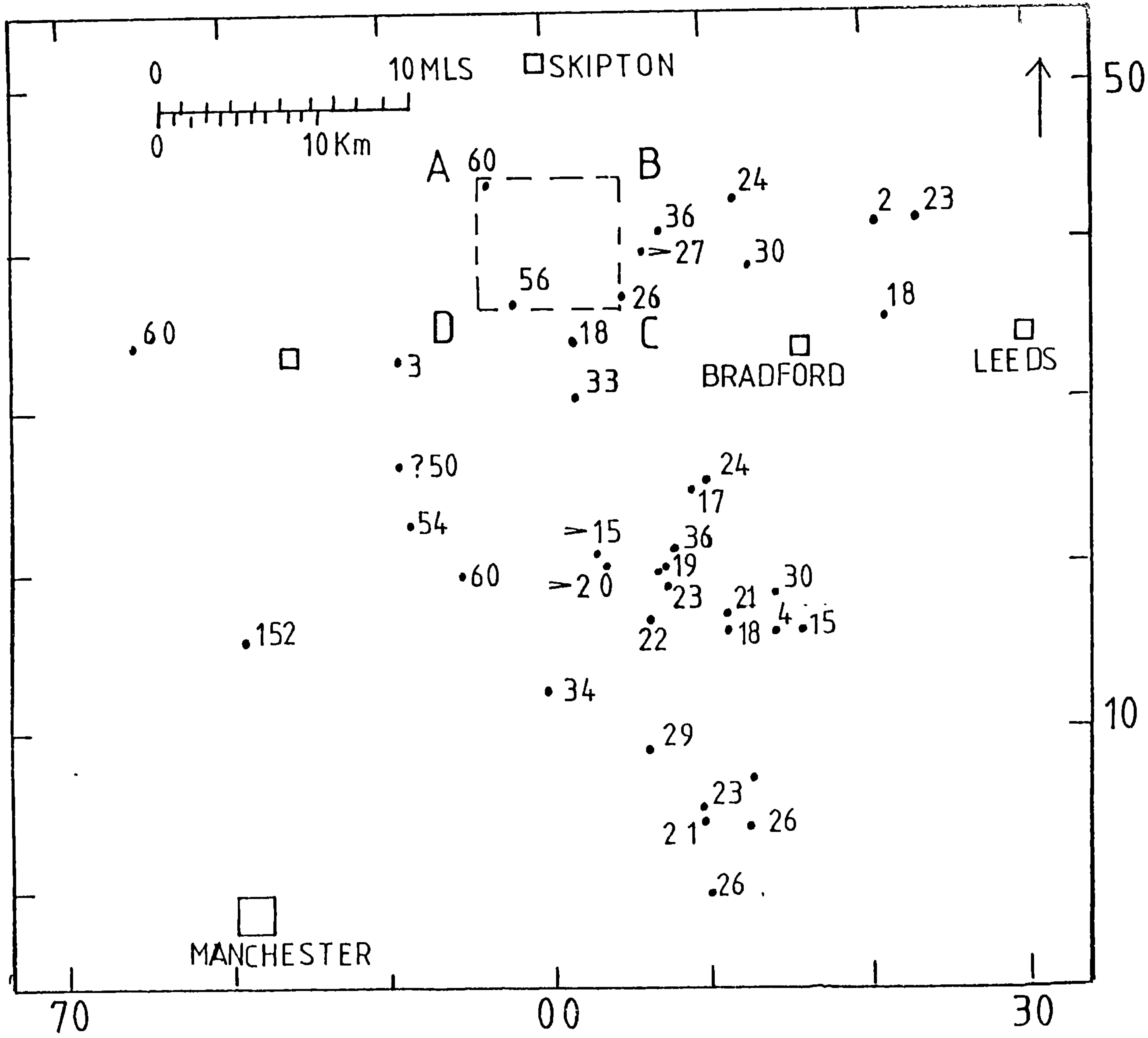

N
50
10
70
00
30
0
10 MLS
0
10Km
SKIPTON
BURNLEY
BRADFORD
LEEDS
MANCHESTER

Fig. 22.

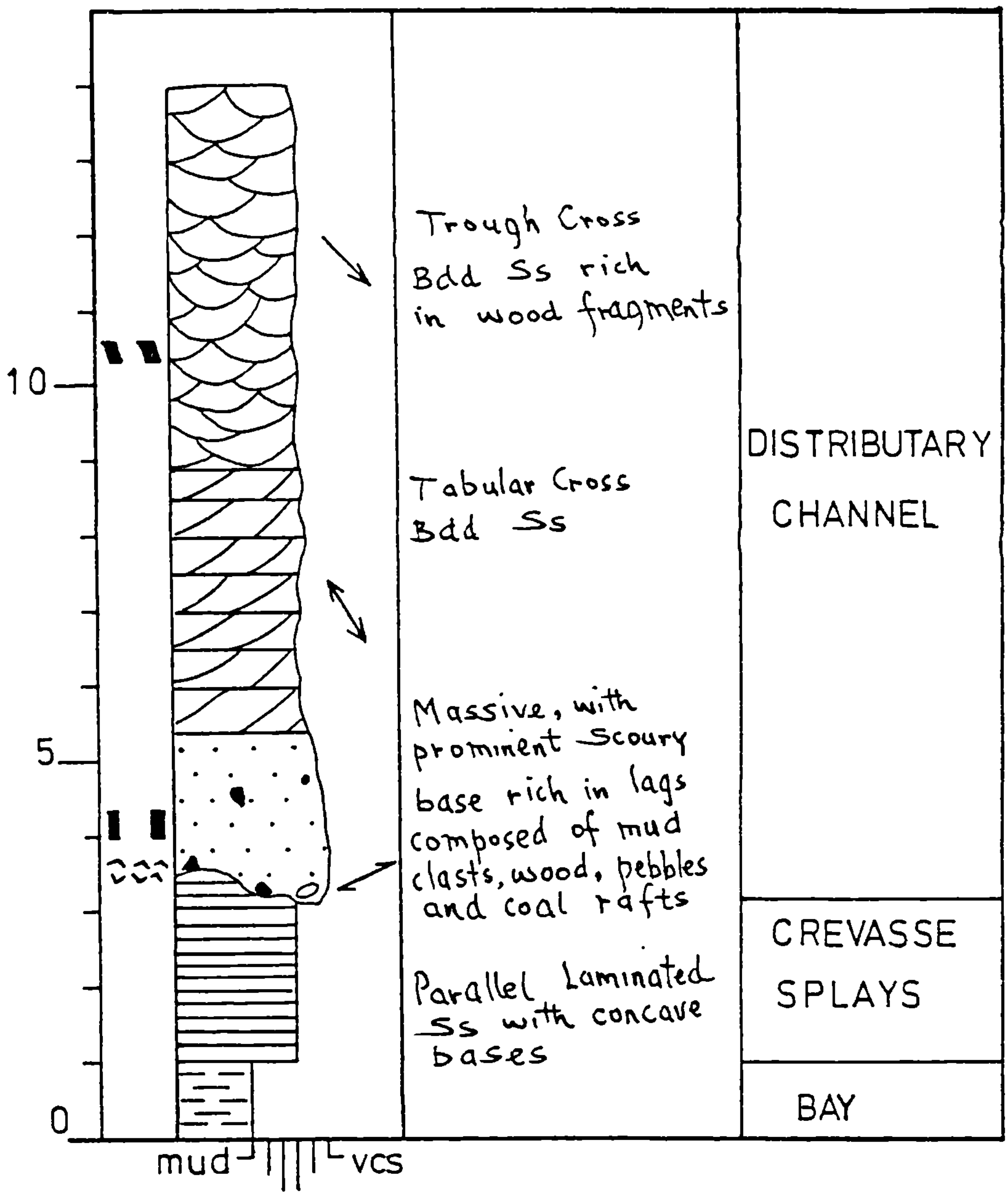
Thickness distribution of Pule Hill Grit. Scale in metres. A B C D is the areal extent of development of Lithofacies 3, Bluestone, in the study area.



SKIPTON
0
10 MLS
0
10 Km
A
B
C
D
60
56
26
18
33
3
60
36
>27
24
30
2
23
18
BRADFORD
LEEDS
?50
54
60
152
>15
>20
24
17
36
19
23
22
21
18
30
4
15
34
29
23
21
26
26
MANCHESTER
50
10
70
00
30

Fig. 23.

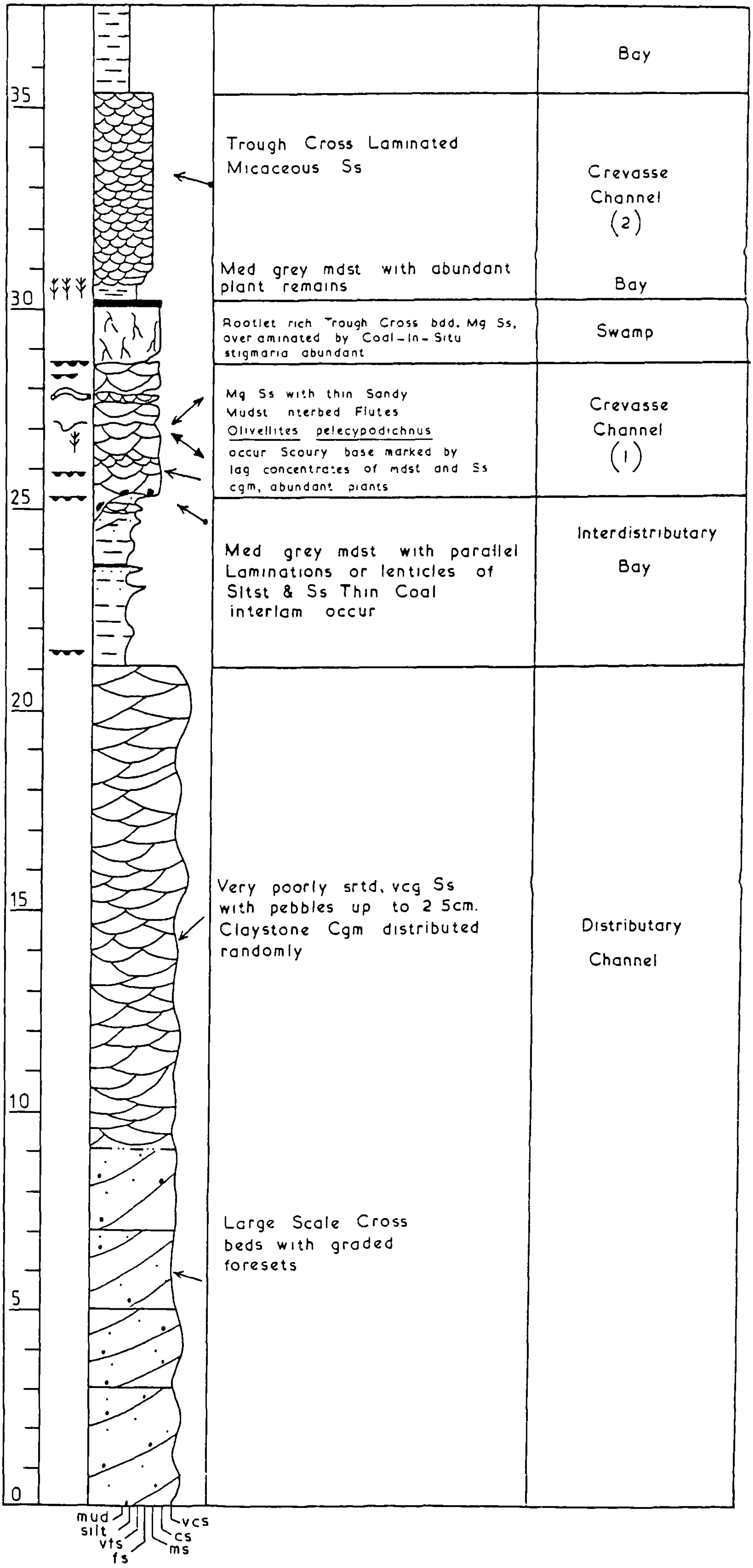
Detailed vertical section of the Pule Hill Grit exposed in Chatterton Wood (SD 795189). See the page opposite Figure 16 for legend (including directional structures).



Trough Cross Bdd Ss rich in wood fragments
Tabular Cross Bdd Ss
Massive, with prominent Scoury base rich in lags composed of mud clasts, wood, pebbles and coal rafts
Parallel Laminated Ss with concave bases
DISTRIBUTARY CHANNEL
CREVASSE SPLAYS
BAY
10
5
0
mud
vcs

Fig. 24.

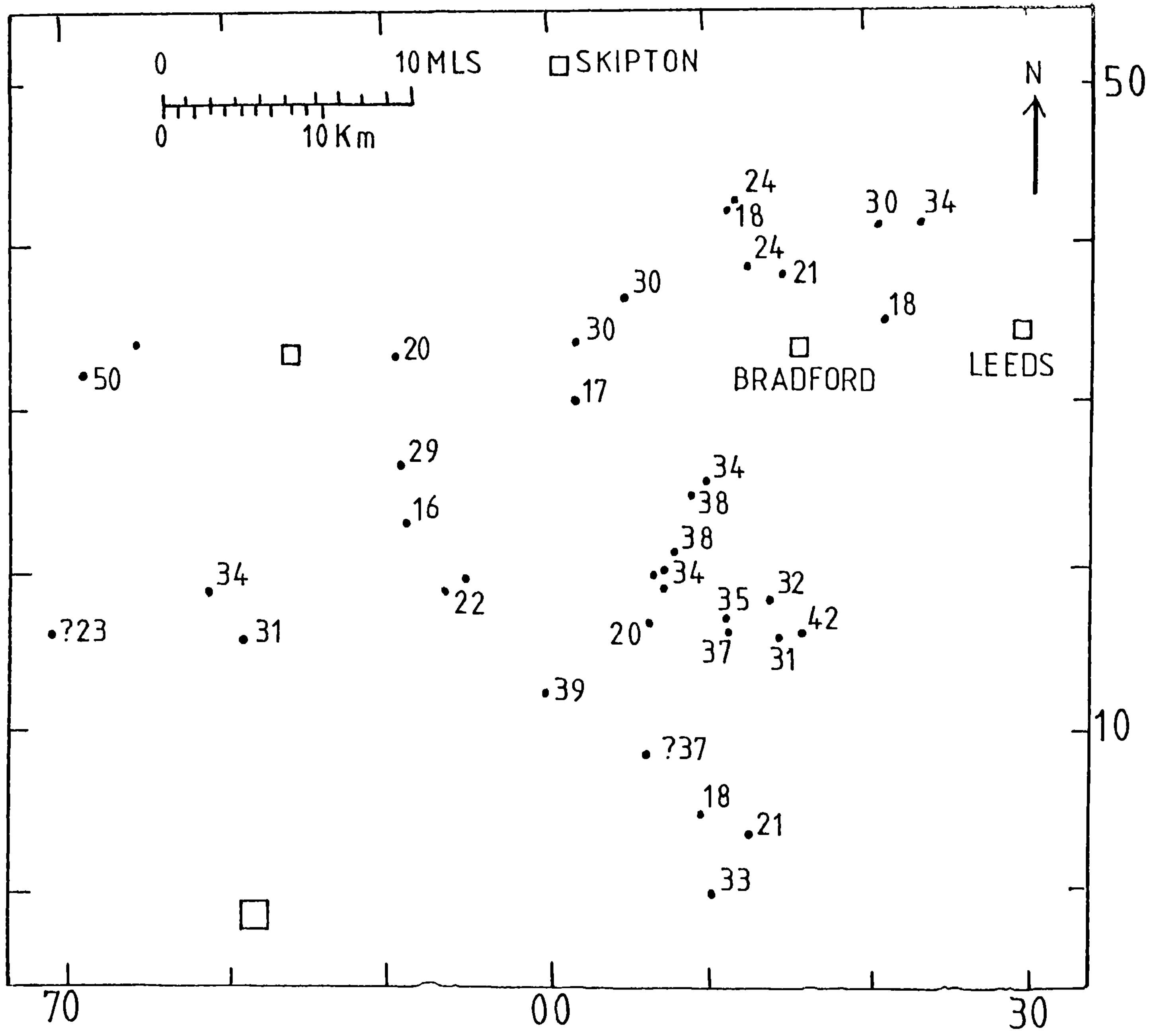
Pule Hill Grit Sequence at Warland Wood Quarries (SD 948203). Scale in metres.



35
30
25
20
15
10
5
0
Bay
Trough Cross Laminated Micaceous Ss
Crevasse Channel (2)
Med grey mdst with abundant plant remains
Bay
Rootlet rich Trough Cross bdd. Mg Ss, over aminated by Coal-In-Situ stigmaria abundant
Swamp
Mg Ss with thin Sandy Mudst nterbed Flutes Olivellites pelecypodichnus occur Scoury base marked by lag concentrates of mdst and Ss cgm, abundant plants
Crevasse Channel (1)
Med grey mdst with parallel Laminations or lenticles of Sltst & Ss Thin Coal interlam occur
Interdistributary Bay
Very poorly srtd. vcg Ss with pebbles up to 2 5cm. Claystone Cgm distributed randomly
Distributary Channel
Large Scale Cross beds with graded foresets
mud
silt
vfs
fs
ms
cs
vcs

Fig. 25.

Thickness distribution of Hazel Greave Interval. Scale in metres.



0
10 MLS
0
10 Km
SKIPTON
N
50
10
BRADFORD
LEEDS
70
00
30
24
18
24
21
30
34
18
30
30
17
20
50
29
16
34
31
22
?23
34
38
38
34
35
32
42
20
37
31
39
?37
18
21
33

Fig. 26.

Thickness distribution of Hazel Greave Grit. Scale in metres.

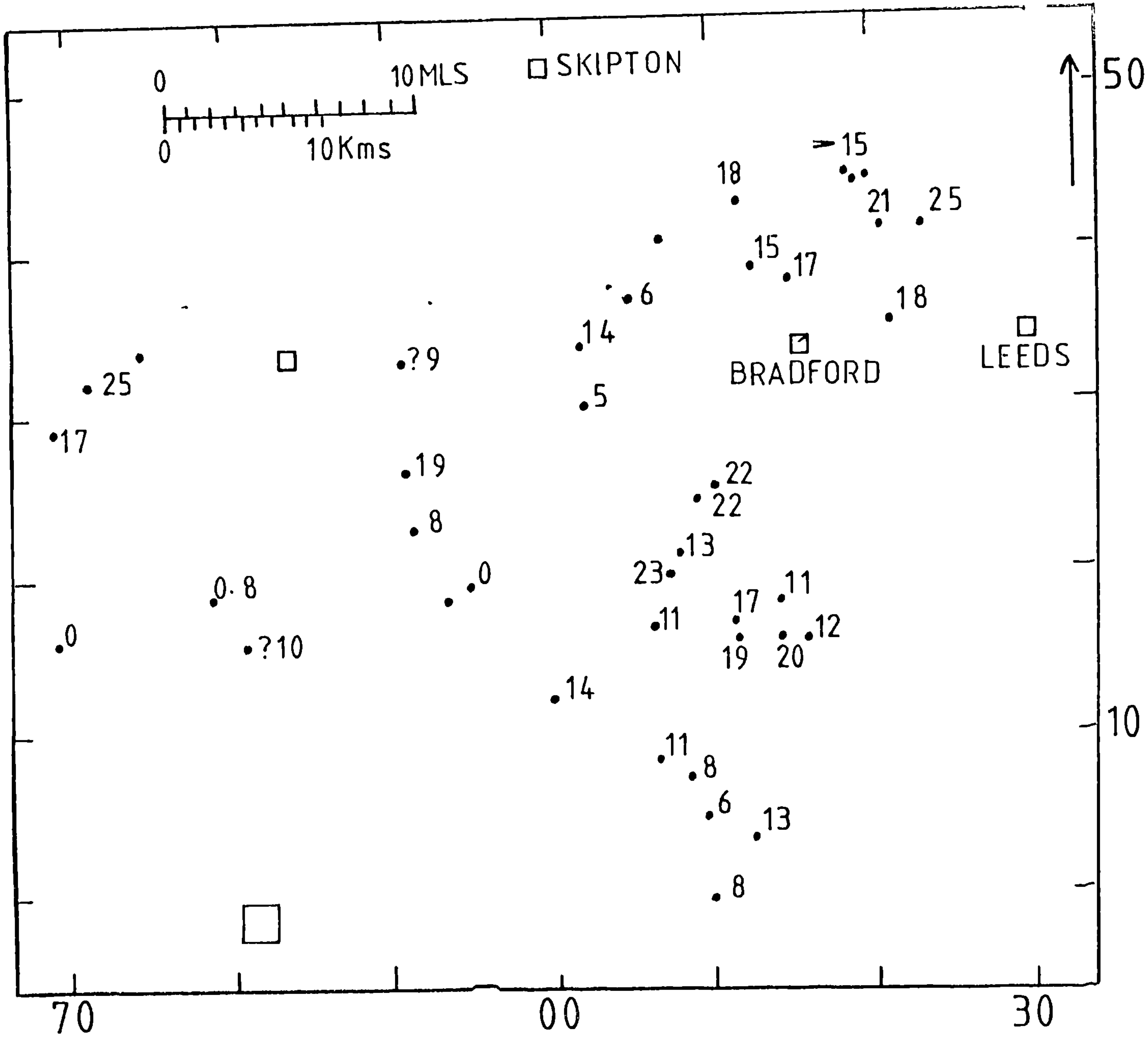
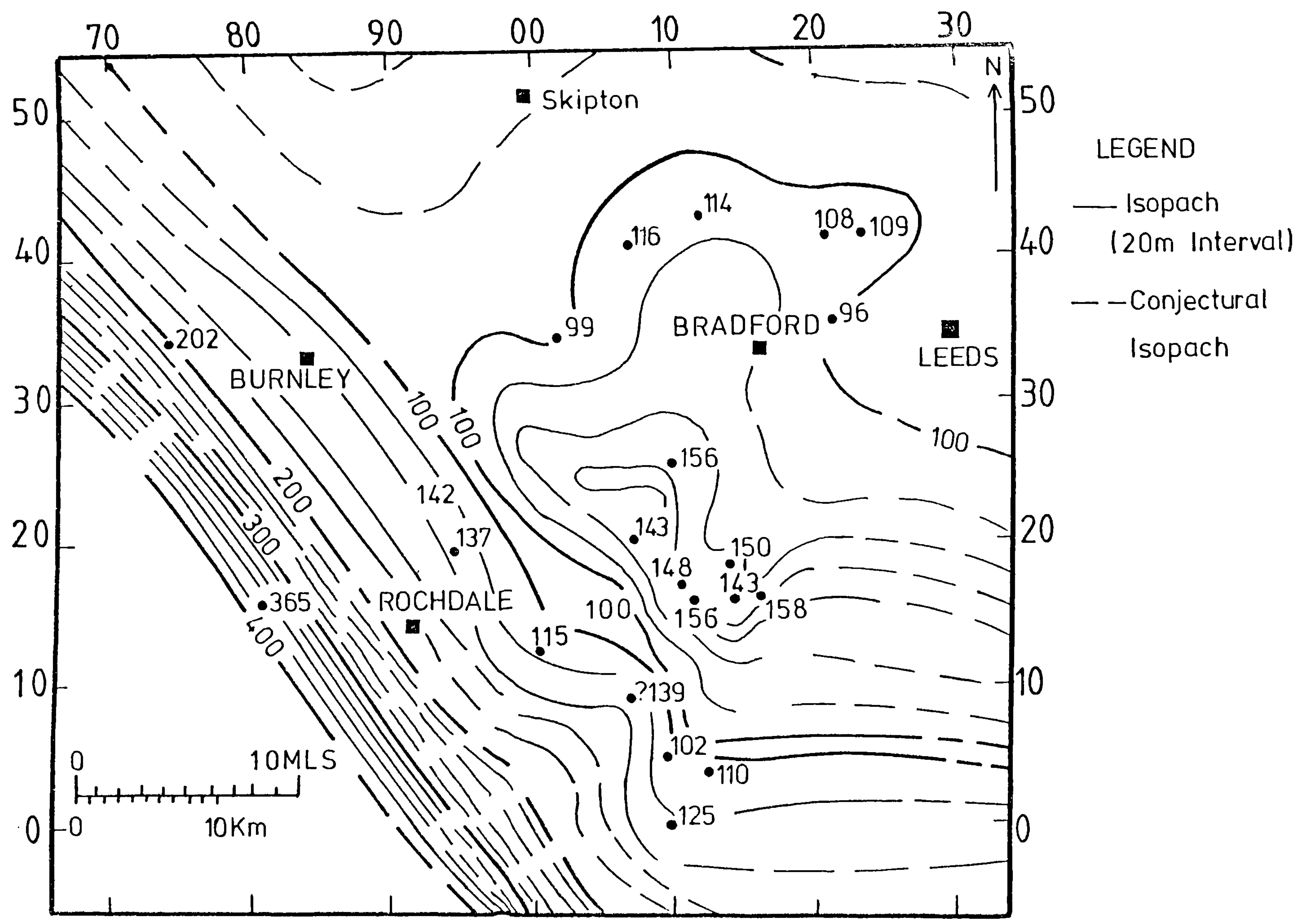

SKIPTON
BRADFORD
LEEDS
0 10MLS
0 10Kms
50
10
70
00
30

Fig. 27.

Isopach map of the Marsdenian Sequence (R_{2A-B}) in the Central Pennine Basin.



70
80
90
00
10
20
30
50
40
30
20
10
0
N
Skipton
BURNLEY
ROCHDALE
BRADFORD
LEEDS
202
365
400
300
200
142
137
100
100
100
115
99
116
114
108
109
96
156
143
148
150
143
156
158
?139
102
110
125
0
10MLS
0
10Km
LEGEND
Isopach
(20m Interval)
Conjectural
Isopach

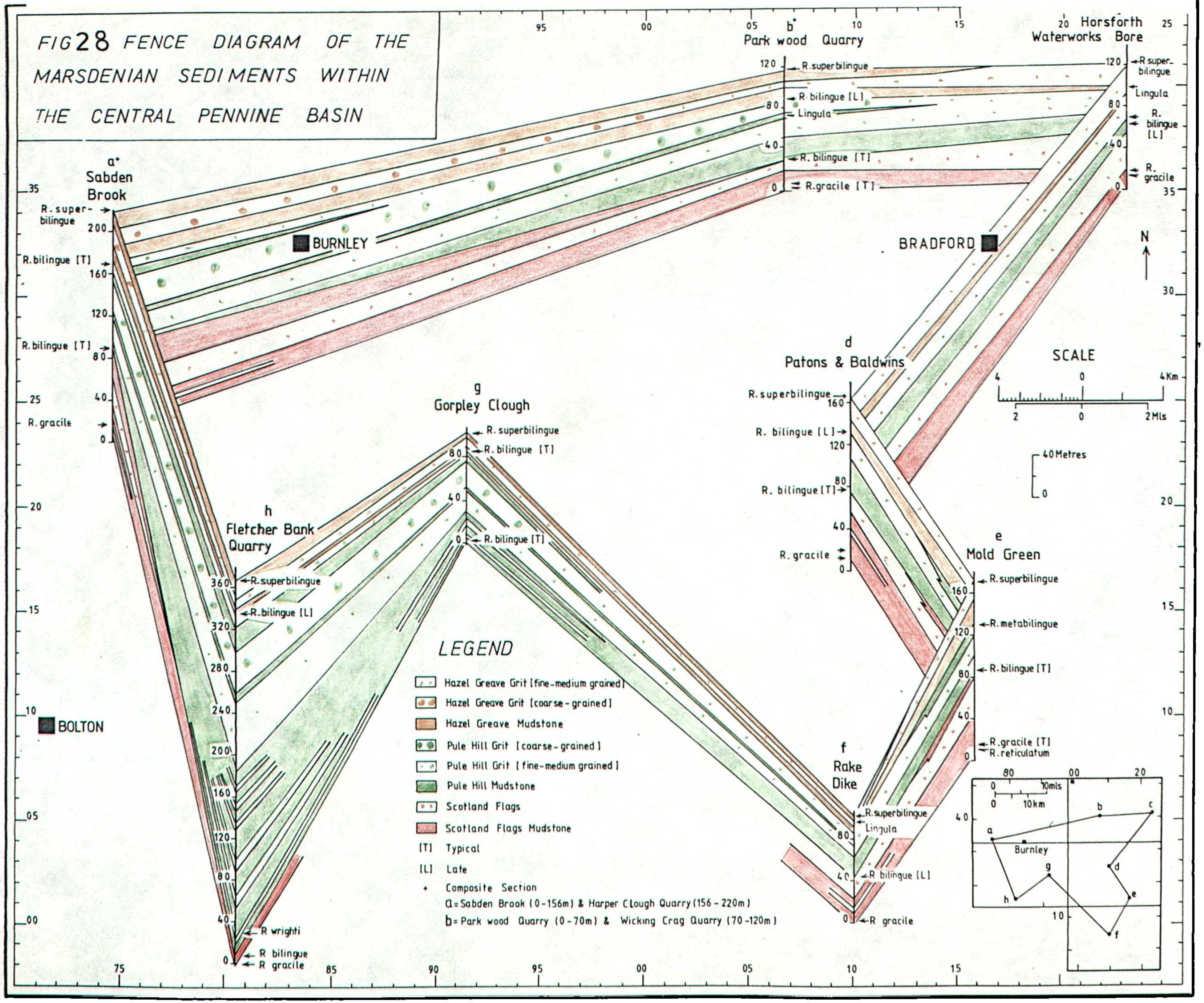


FIG 28 FENCE DIAGRAM OF THE MARSDENIAN SEDIMENTS WITHIN THE CENTRAL PENNINE BASIN

Fig. 29.

Detailed vertical section in the Delta Slope Association in Longworth Valley Exposure (SD 689157) showing the bands of R. bilingue late, R. metabilingue, R. superbilingue and the slumped and unslumped layers within the section. (See legend opposite Fig. 16 for explanations of the notations used).

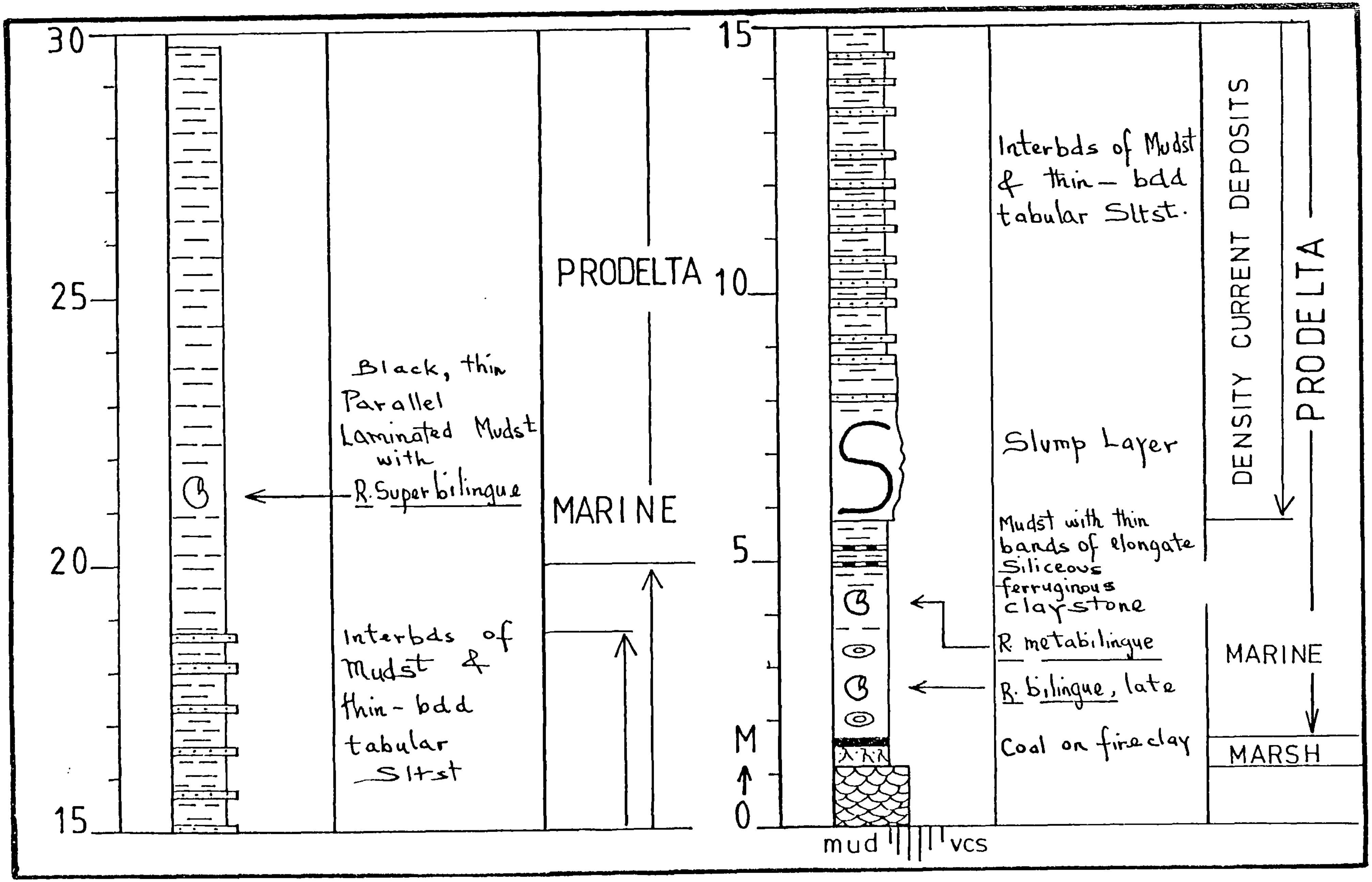

30
25
20
15
Black, thin Parallel Laminated Mudst with R. Superbilingue
Interbds of Mudst & thin-bdd tabular Sltst
PRODELTA
MARINE
15
10
5
M
0
mud
vcs
Interbds of Mudst & thin-bdd tabular Sltst.
Slump Layer
Mudst with thin bands of elongate Siliceous ferruginous claystone
R. metabilingue
R. bilingue, late
Coal on fireclay
DENSITY CURRENT DEPOSITS
PRODELTA
MARINE
MARSH

Fig. 30.

Traced sketch of photograph (Plate 18) showing slumped and unslumped horizons (Density current deposits within the Slope Association) occurring in the Hazel Greave Mudstone of Longworth Valley Exposure (SD 689157, level 2-22m, Fig. 29). Note the positions of Plate 20 and 21. A B C D is the areal extent of Plate 19 which is the same as Figure 31. Note the levels of the bands of *R. bilingue* late, *R. metabilingue* and *R. superbilingue*. Man on ladder is 1.5m tall.

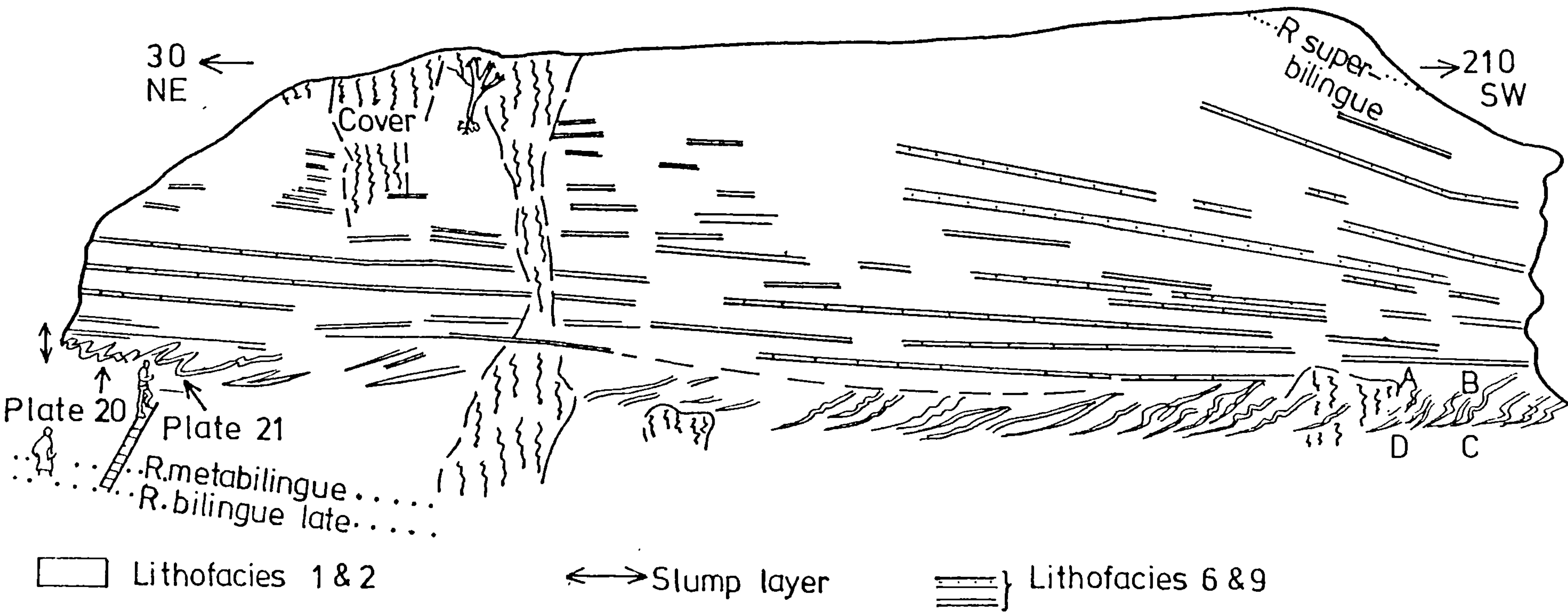
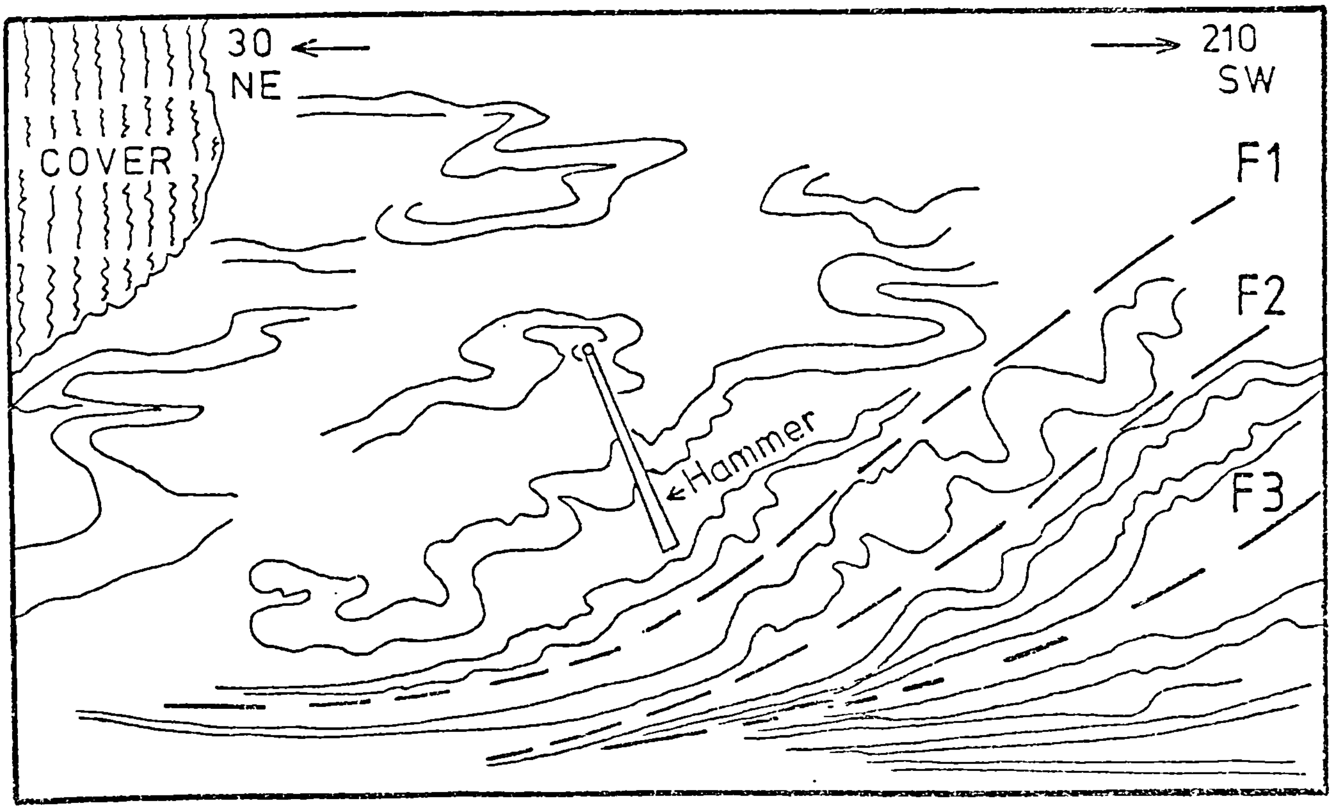

30 NE
210 SW
R super-bilingue
Cover
A
B
C
D
Plate 20
Plate 21
R.metabilingue
R.bilingue late
Lithofacies 1 & 2
Slump layer
Lithofacies 6 & 9

Fig. 31.

Traced sketch of photograph (Plate 19) outlining the interpreted thrust plans F', F2, F3 which brought several limbs of many folds in close contact with one another particularly in the lower parts of the Slump Zone. (Longworth Valley Exposure. Hammer is 33cm long).



COVER
30
NE
210
SW
F1
F2
F3
Hammer

Fig. 32.

Orientation data from slump folds in Hazel Greave Mudstone (Prodelta) Longworth Valley Exposure. (SD 689157 at 30^{0} class interval.

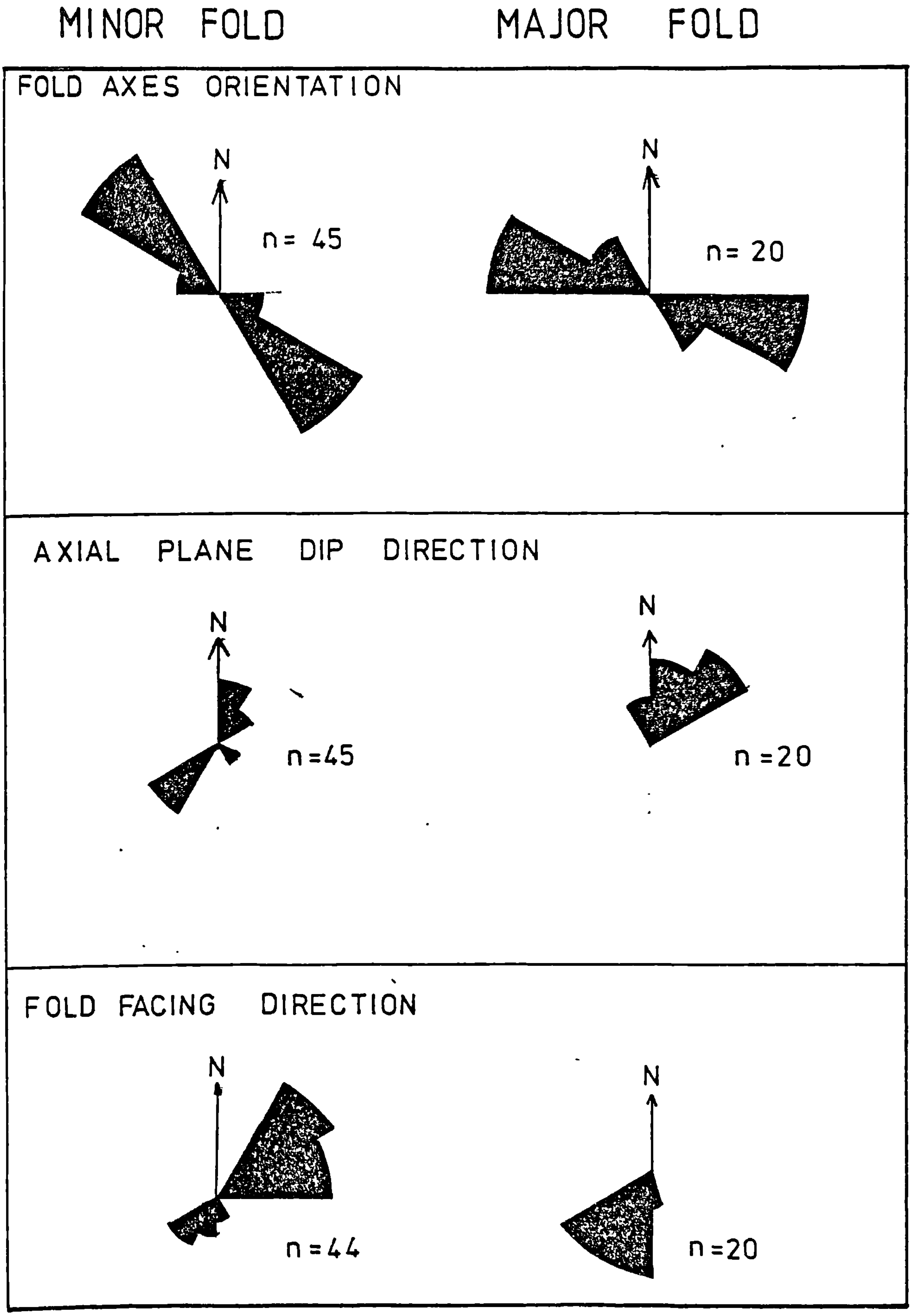

MINOR FOLD
MAJOR FOLD
FOLD AXES ORIENTATION
N
n= 45
N
n= 20
AXIAL PLANE DIP DIRECTION
N
n=45
N
n=20
FOLD FACING DIRECTION
N
n=44
N
n=20

Fig. 33.

Processes that generated the slumping Hazel Greave Mudstone at Longworth Valley. (SD 689157). (See page 102 of volume 1).

Fig. 34.

Rose diagram showing the multi-directional dip direction on top of Beds of Scotland Flags in Ramsden Clough. (23-40m level, Fig. 57, SE 121038).

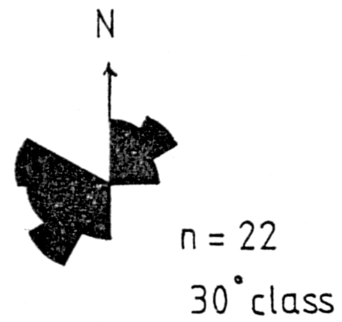
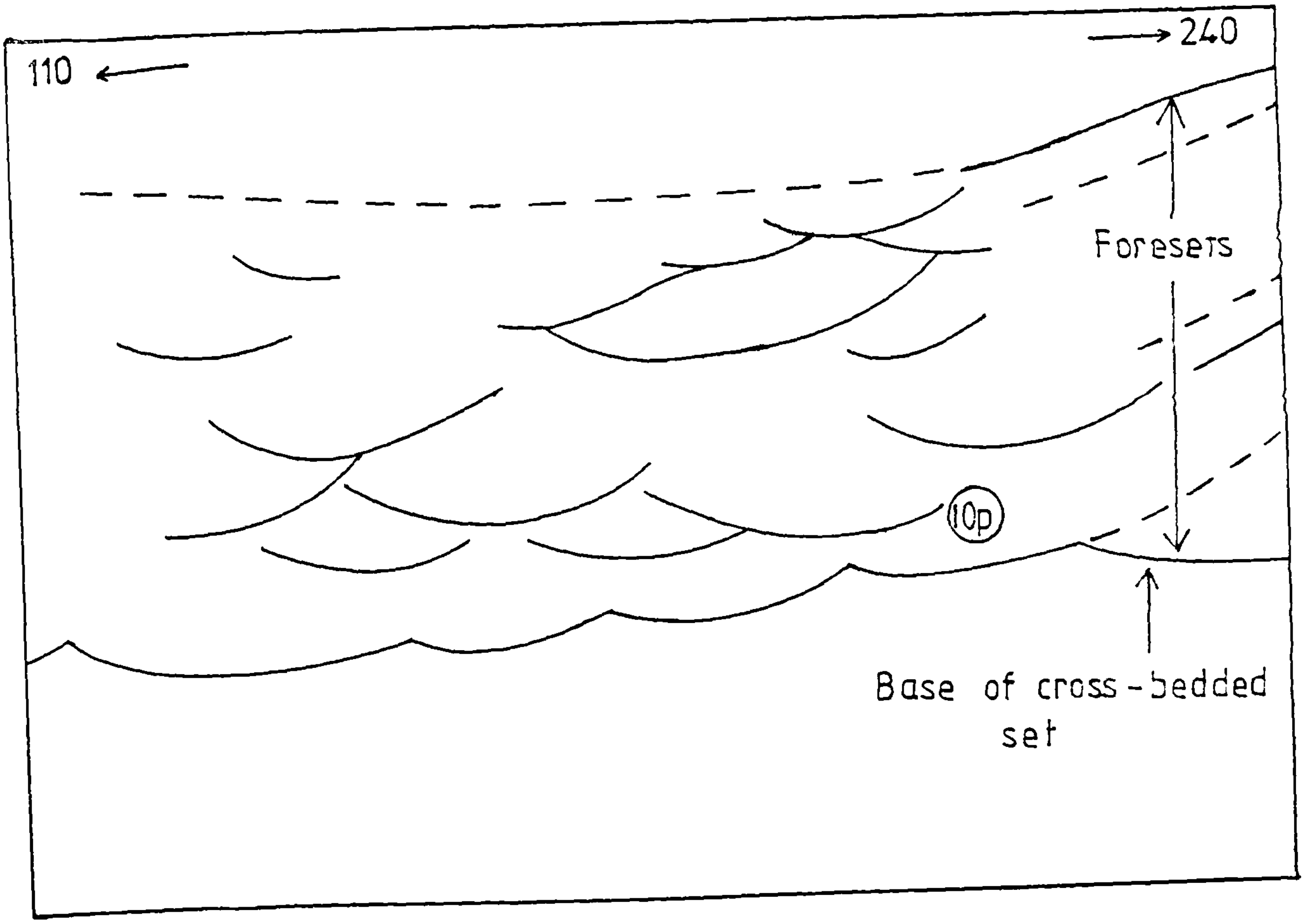

N
n = 22
30° class

Fig. 35.

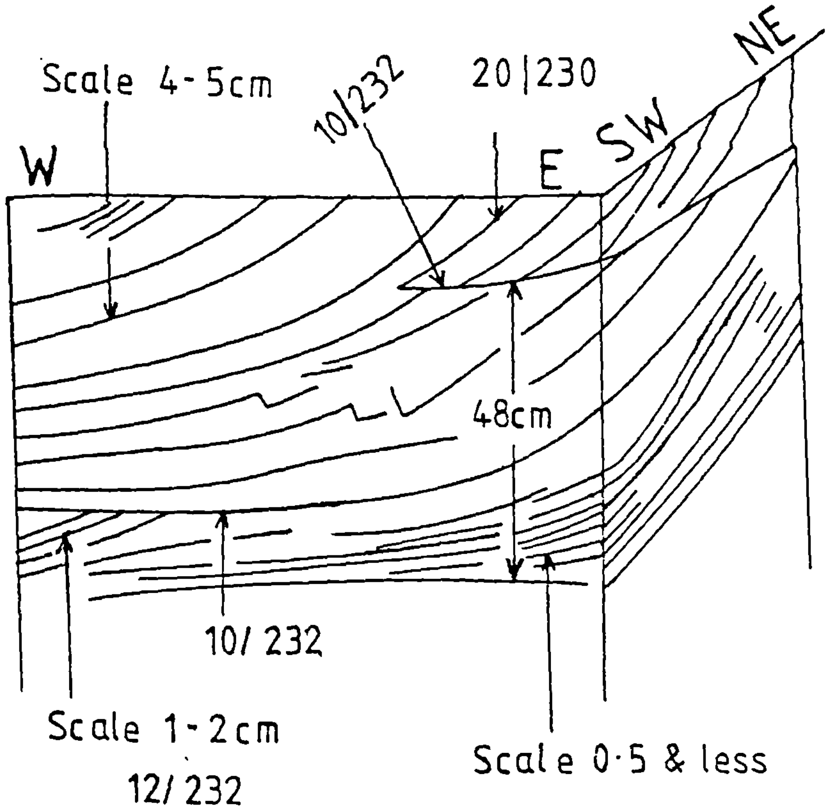
Traced sketch of photograph (parts of Plate 28) showing lithofacies 10, Trough Cross Bedded Sandstone as transverse intraset (falling water stage feature) of angular foresets in the Hazel Greave Grit exposed in Wicking Crag Quarry (SE 049374, level 60m, 'b' sequence, Fig. 15). (Intraset occurs from the level of the ten pence piece to the dashed 'upper' boundary of bed; ten pence piece is 29mm in diameter).

Fig. 36.

Internal Erosion surface in lithofacies 11, Tabular Cross Bedded Sandstone in Pule Hill Grit sequence of Lumb Quarry (SE 031211).



110
240
Foresets
10p
Base of cross-bedded set



Scale 4-5cm
10/232
20|230
NE
SW
W
E
48cm
10/ 232
Scale 1-2cm
12/ 232
Scale 0·5 & less

Fig. 37.

Traced sketch of photograph (Plate 49) illustrating the slumped and unslumped horizons (Distributary Channels) in the Scotland Flags exposed in the middle parts of Riverside Cemetary Quarry (SE 053237) Sowerby Bridge. The unslumped lower zone is occupied by Lithofacies 13, Scour Based Sand bodies (Plate 65 is from this zone).

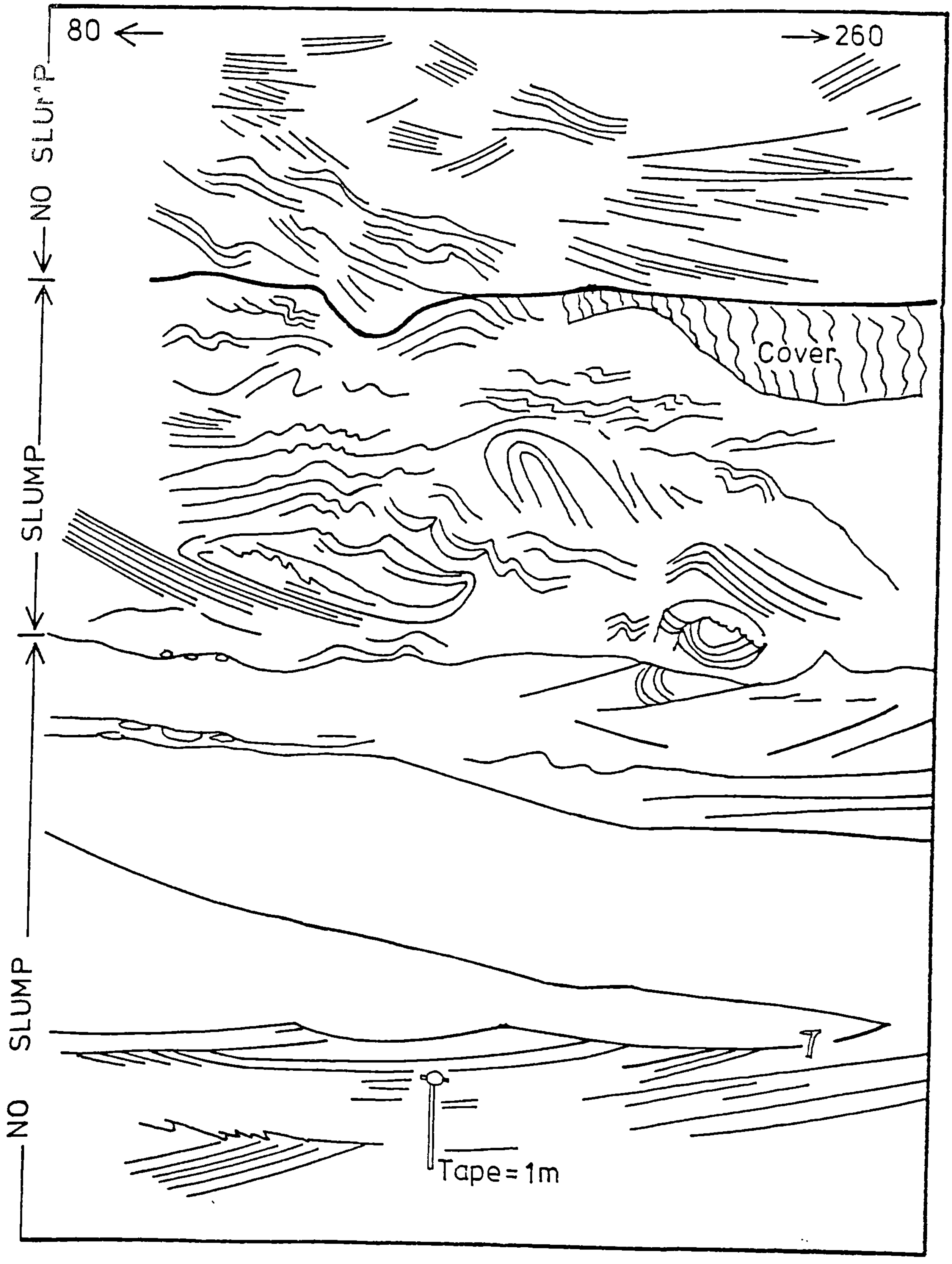
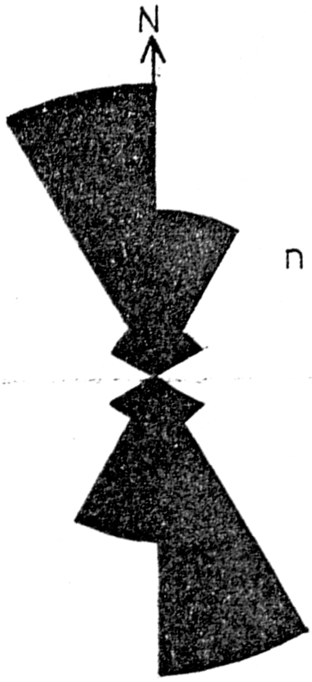

80
260
NO SLUMP
SLUMP
Cover
SLUMP
NO
Tape = 1m

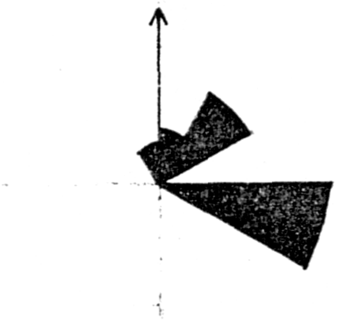
Fig. 38.

Azimuthal plot of the orientation of folds in the slumped Scotland Flags (Distributary Channels) exposed in Riverside Cemetary Quarry (SE 053237), Sowerby Bridge.



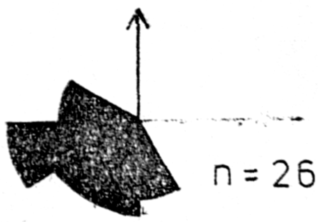
n = 37

FOLD AXIS
ORIENTATION



n = 36

AXIAL PLANE
DIP DIRECTION



n = 26

FOLD FACING
DIRECTION

Fig. 39.

Sereonet plot of folds axis orientation in the slumped Scotland Flags (Distributary Channels) exposed in Riverside Cemetary Quarry (SE 053237), Sowerby Bridge.

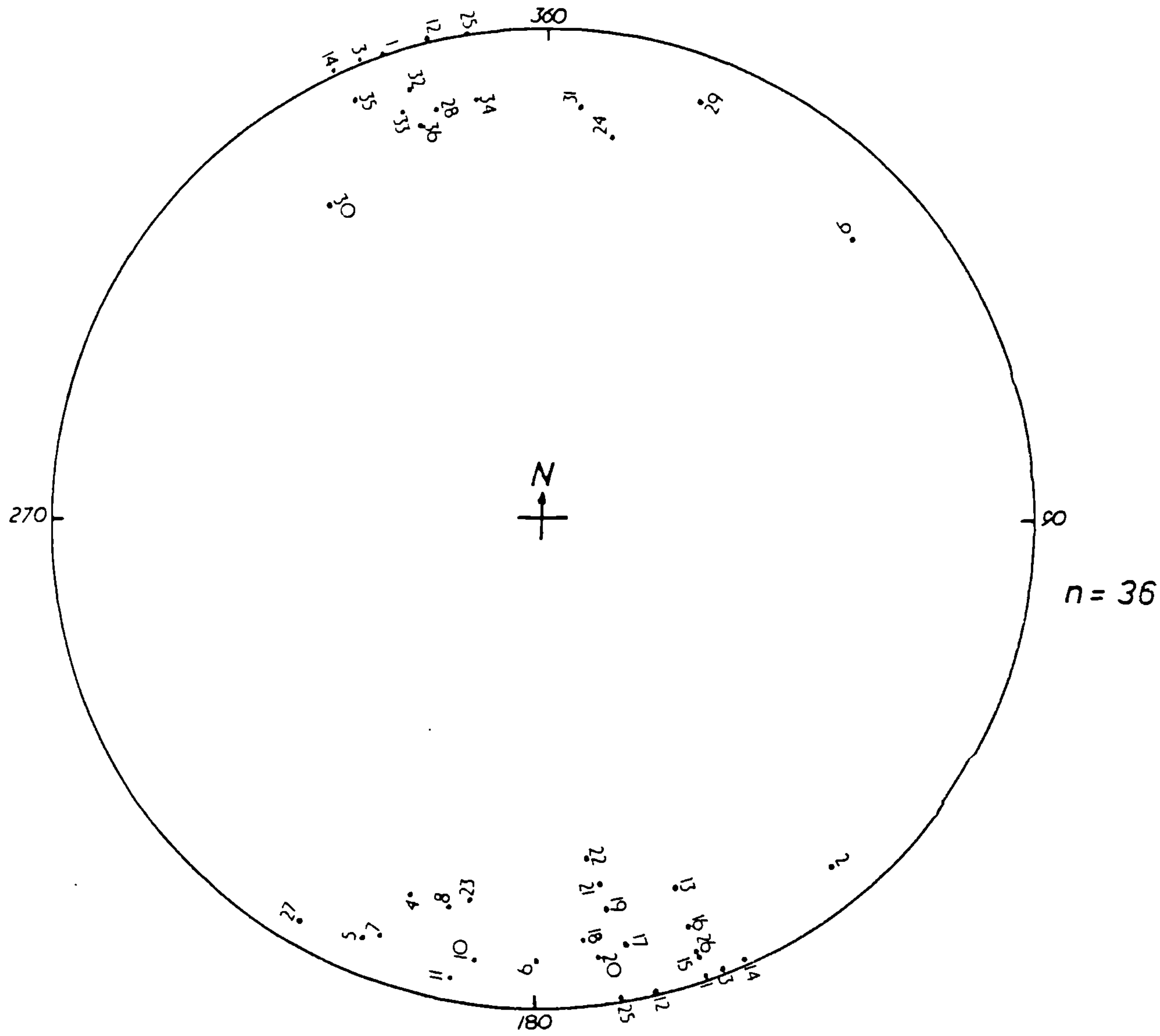

360
270
90
180
N
n = 36

Fig. 40.

Stereonet plot of the Poles to axial surfaces in the slumped Scotland Flags (Distributary Channels) exposed in Riverside Cemetary Quarry (SE 053237), Sowerby Bridge.

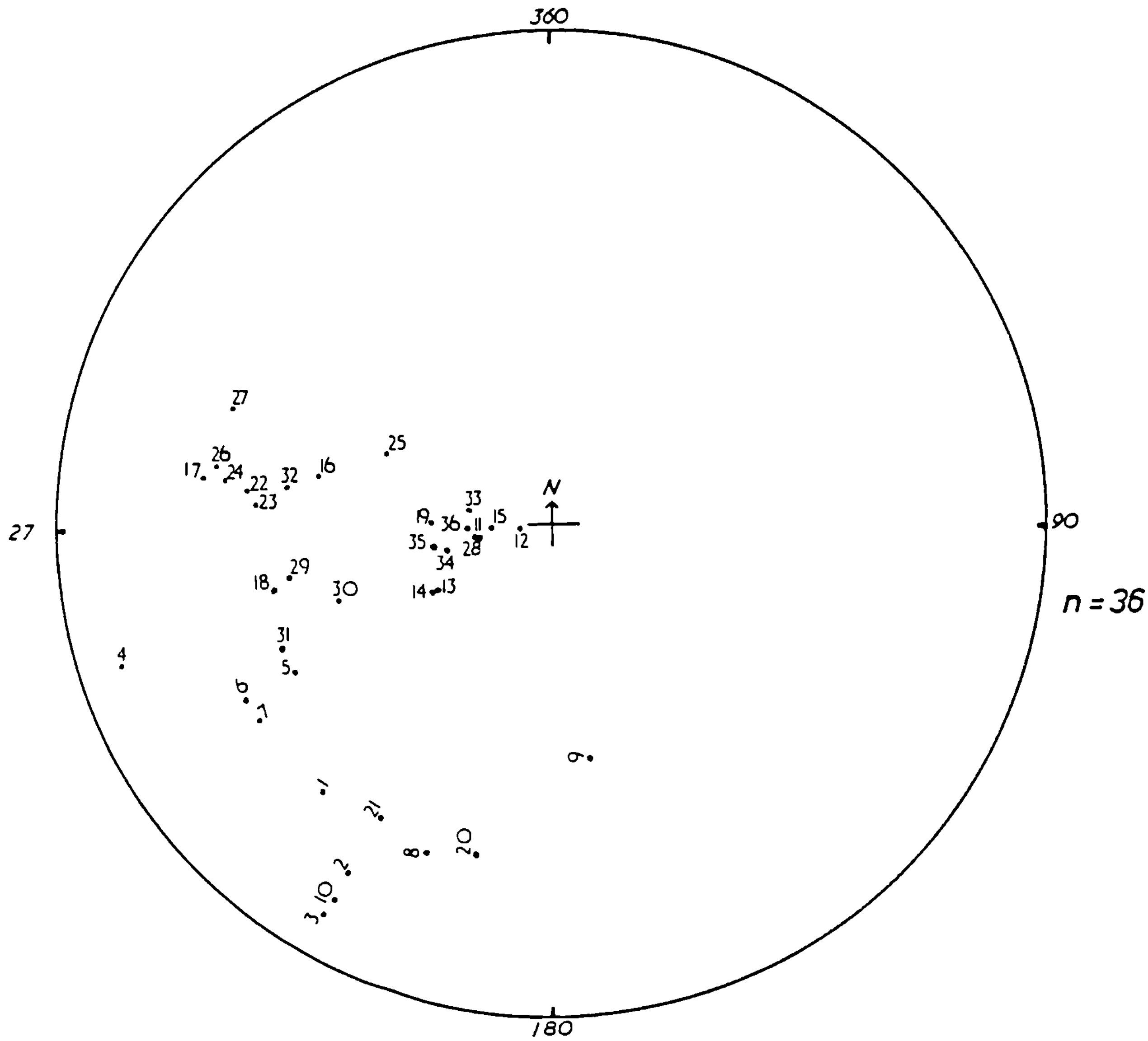
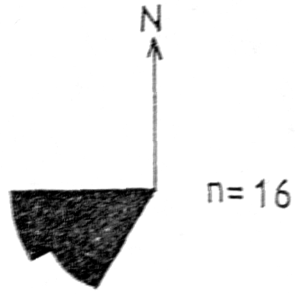

360
27
90
180
N
n = 36

Fig. 41.

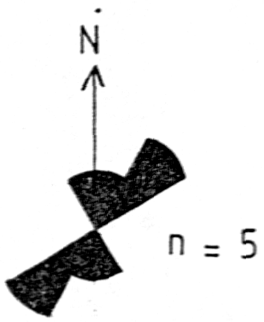
Palaeocurrent pattern in unslumped sedimentary structures related to the slumped zones in the Scotland Flags (Distributary Channels) exposed in Riverside Cemetary Quarry (SE 053237), Sowerby Bridge.

TROUGH IN SMALL
CHANNEL BELLOW THE
SLUMPED ZONE

CROSS BEDDING IN UNSLUMPED
PARTS OF THE SLUMPED LAYER



PLANTS IN THE SMALL
CHANNELS



RIPPLES IN SLUMPED
ZONE

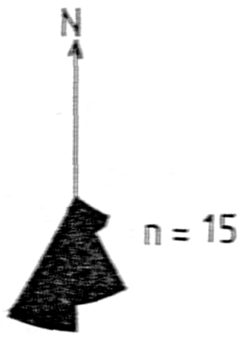
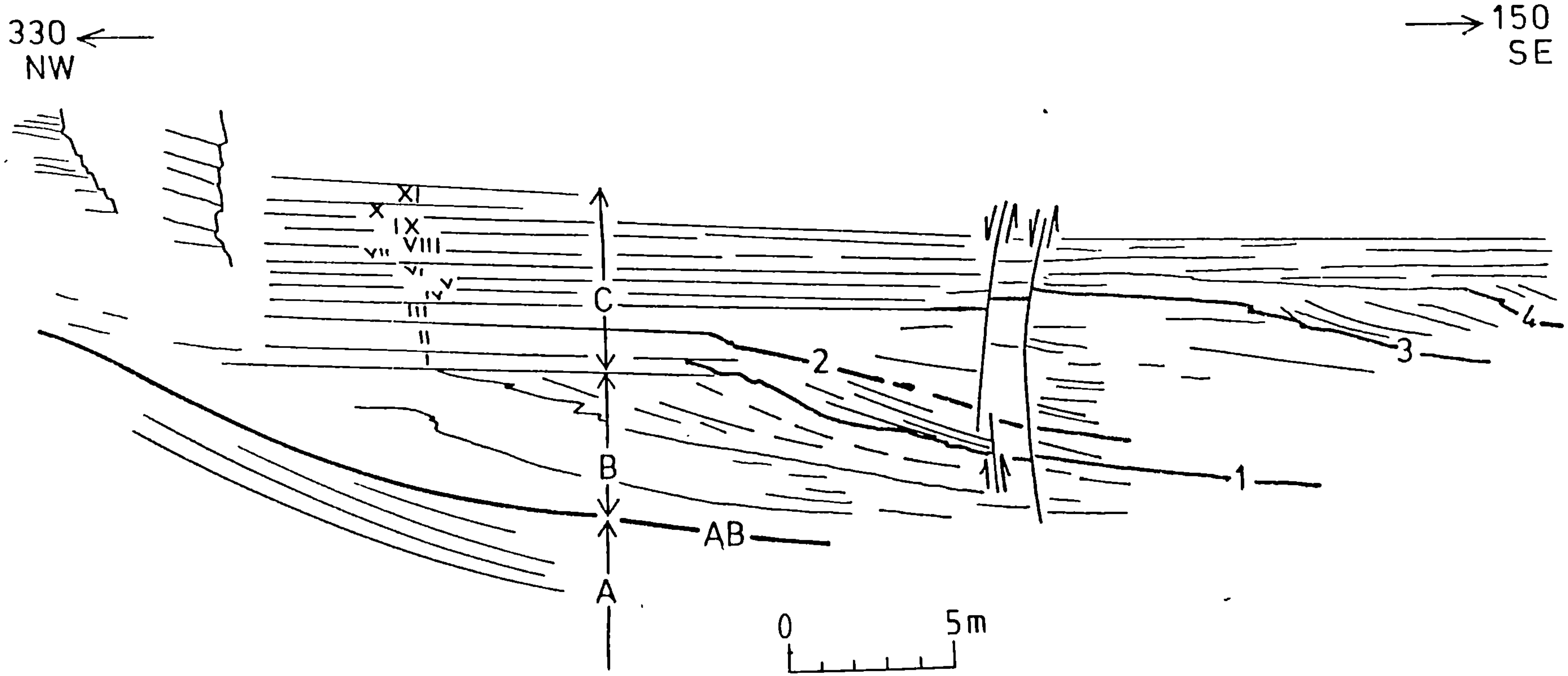


Fig. 42.

Traced sketch of photograph (Plate 53) showing lithofacies 12, Large Scale Cross-bedding with low-angle foreset (in A), and concave upward foresets in (B). Note the sandy mudstone drape (AB), the internal erosion surface 1, 2, 3, 4, and the grading southeastwards of lithofacies 14, Horizontal bedded Sandstone (C), into lithofacies 12, Large Scale Cross Bedding. (A, B, C are Scotland Flags Channel Units in Diggley Quarry, SE 110094, near Holmfirth).



330 NW
150 SE
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
C
B
A
AB
1
2
3
4
0
5m

Fig. 43.

Traced sketch of photograph (Plate 60) of the NW-SE face of Quarry in Ramsden Clough, showing southeasterly gradation of lithofacies 10, Trough Cross Bedded Sandstone (See B2, B3) to lithofacies 12, Large Scale Cross Beds. Note the following: internal erosion surface 'E' truncating its underlying cross beds (B1); Gradational contact between Lithofacies 14 (See A-Beds) and the Large Scale Cross Beds (B1); internal stratification within B2 to B6 indistinct.

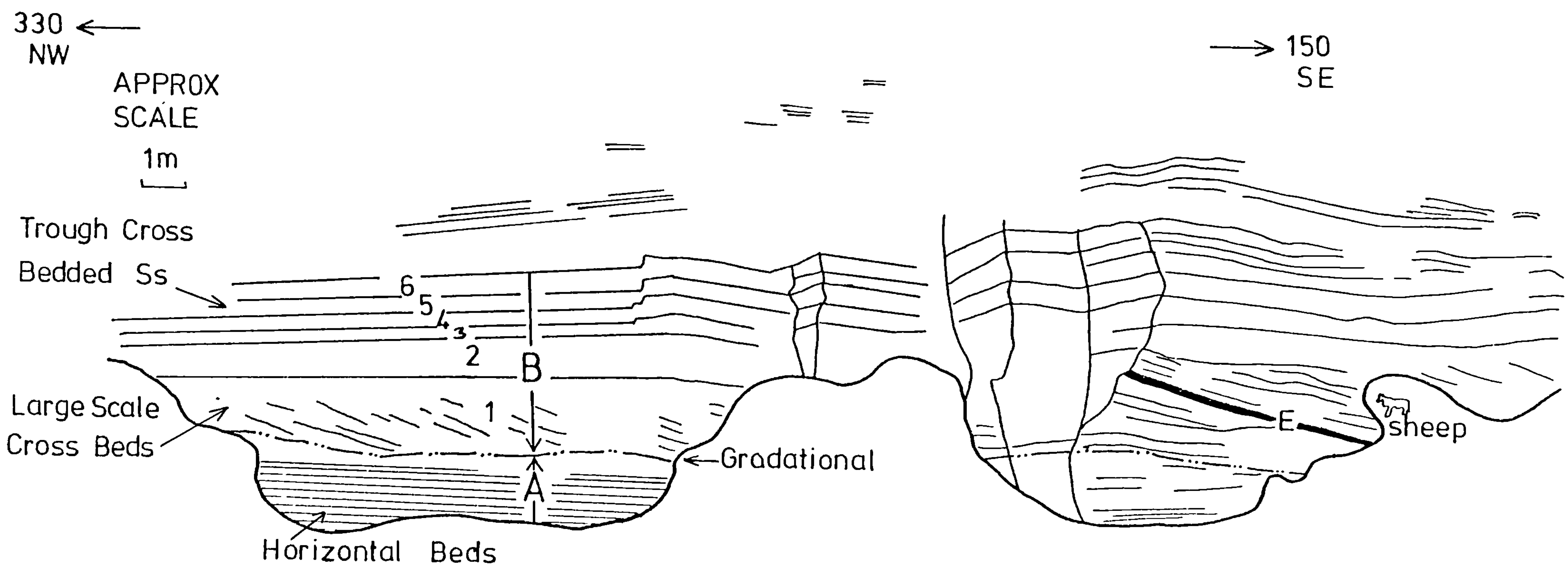

330 NW
150 SE
APPROX SCALE
1m
Trough Cross Bedded Ss
6
5
4
3
2
1
B
A
Large Scale Cross Beds
Gradational
Horizontal Beds
E
sheep

Fig. 44.

Traced sketch of photograph (Plate 61) which represents the Central one-third of the overall quarry exposure in Ramsden Clough. Internal erosion surface 'E' is the south-east continuation of the 'E' in Figure 43. Note the Lenticular beds (Lb) which overlie 'E', the overlapping behaviour of the undulatory foresets (arrowed) of Lithofacies (LF) 12, Large Scale Cross Beds, in a southeast progression. XX' represents the lateral extent of Plate 61 which constitutes Plate 63.

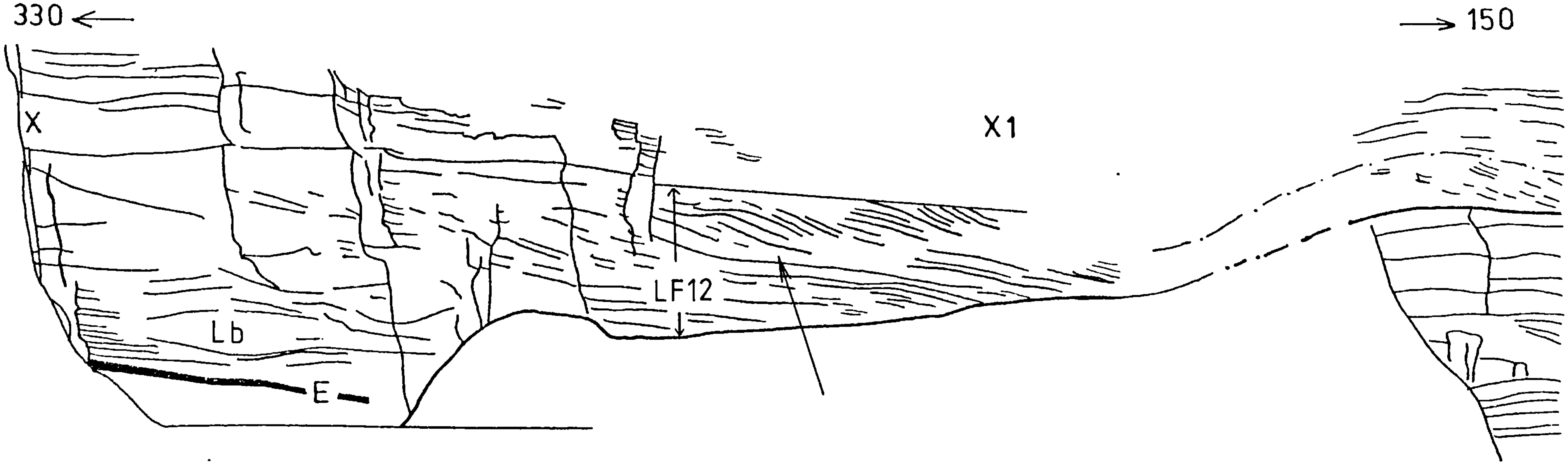

330
150
X
X1
LF12
Lb
E

Fig. 45.

Traced sketch of photograph (Plate 62) which occurs southeast of Figure 44 and represents the southeast one-third of the overall quarry exposure in Ramsden Clough. Note the internal erosion surface 'EE' truncating the underlying cross beds of Lithofacies 12, Large Scale Cross-Bedding (See Fig. 66a' which is the field sketch of the quarry face covered by Plate 62).

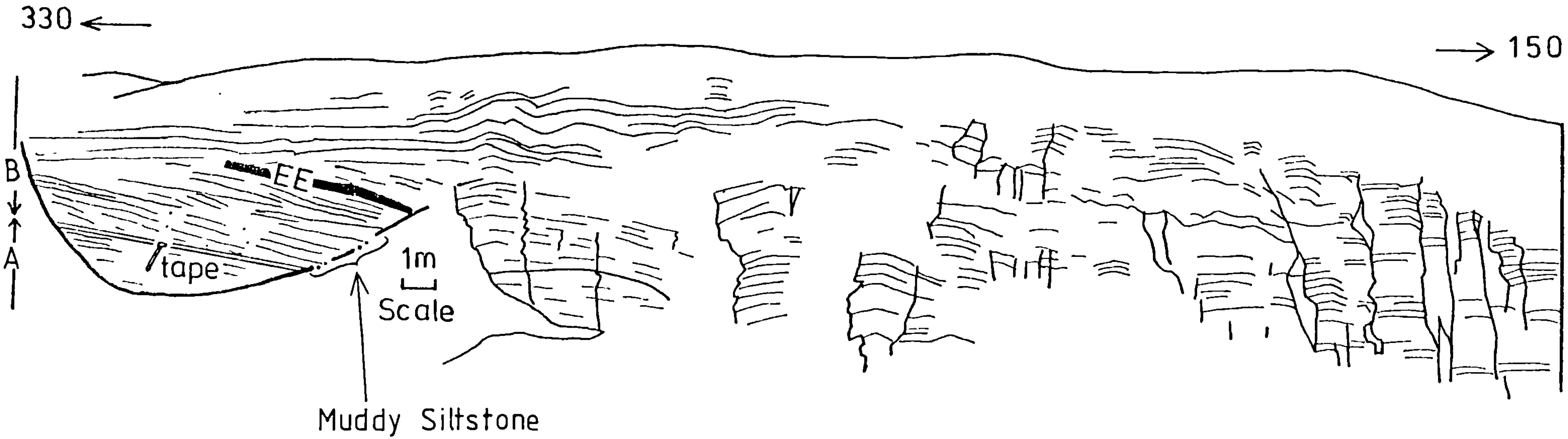
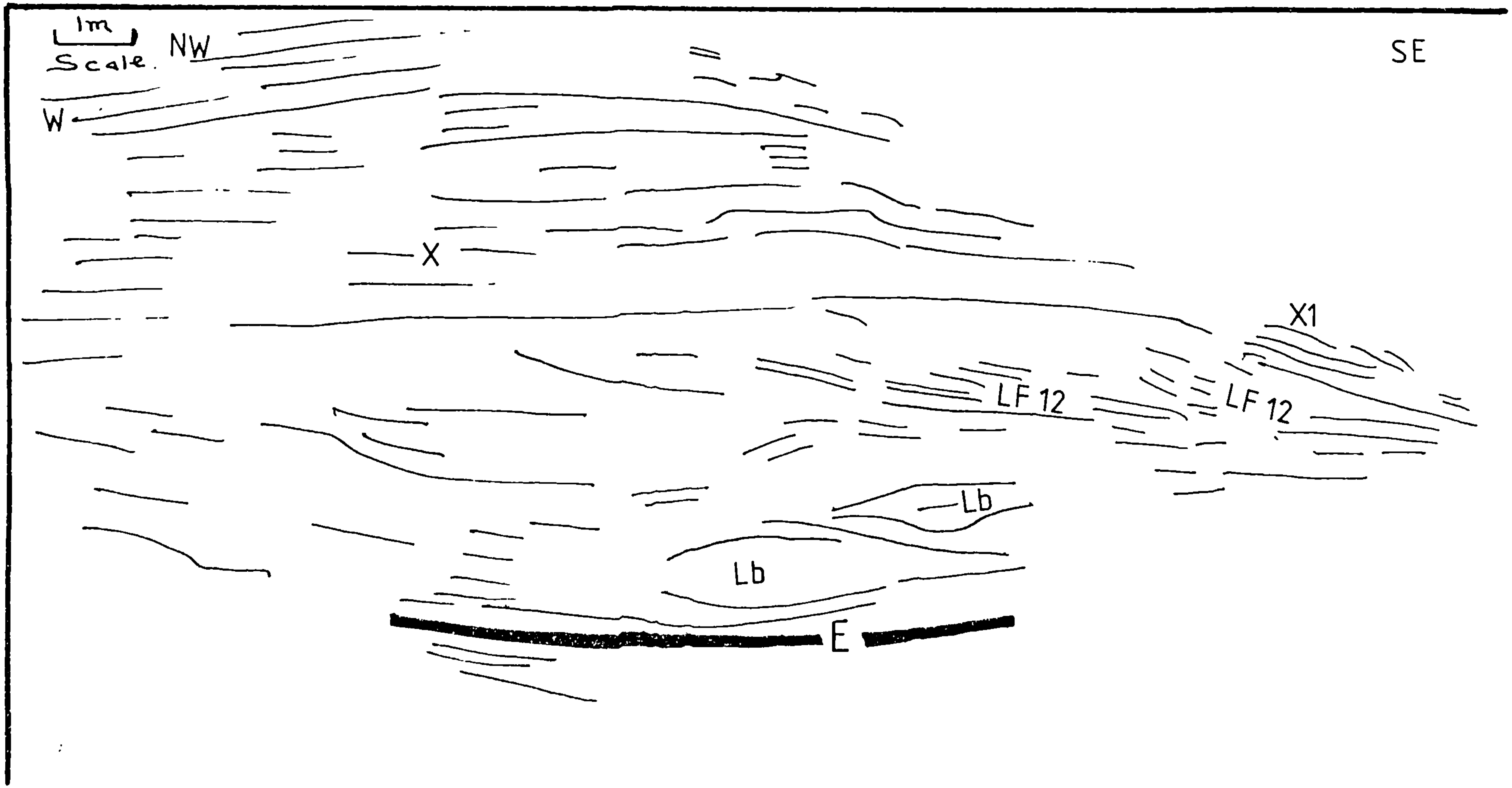

330
150
B
A
EE
tape
1m
Scale
Muddy Siltstone

Fig. 46.

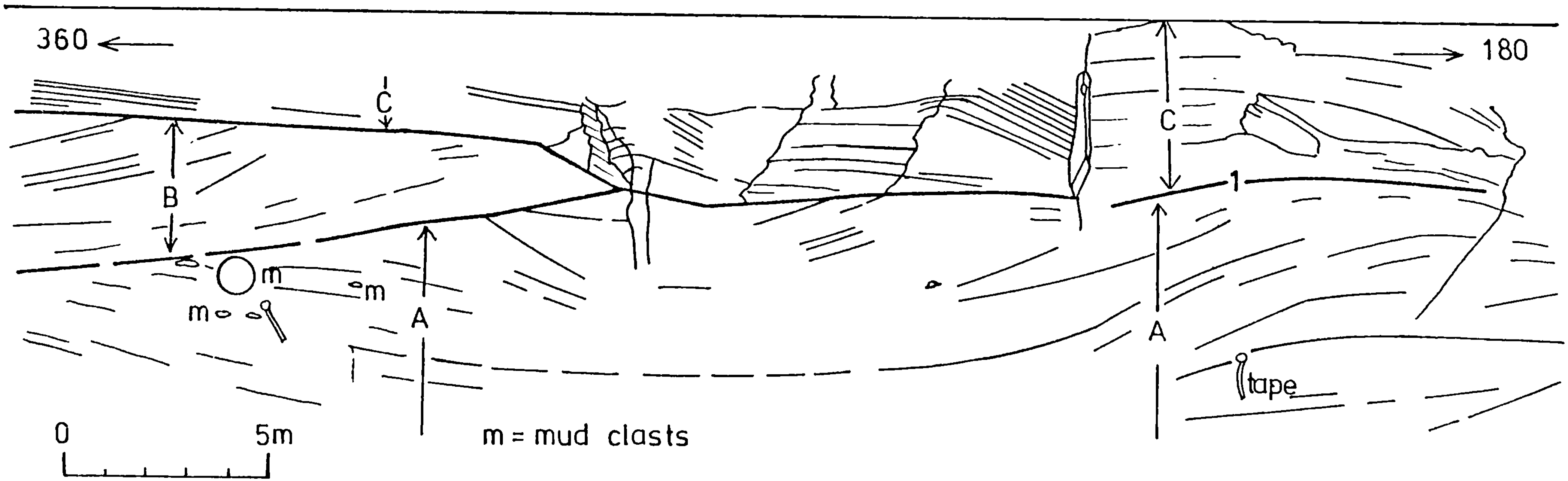
Traced sketch of photograph (Plate 63) illustrating the relationships between the internal erosion surface 'E', the lenticular beds (Lb) and lithofacies (LF) 12, Large Scale Cross Bedding. Notations 'W XXI' also in Plates 60, 61 and 63 aid correlation between the feature in these plates.



1m
Scale
NW
SE
W
X
X1
LF 12
LF 12
Lb
Lb
E

Fig. 47.

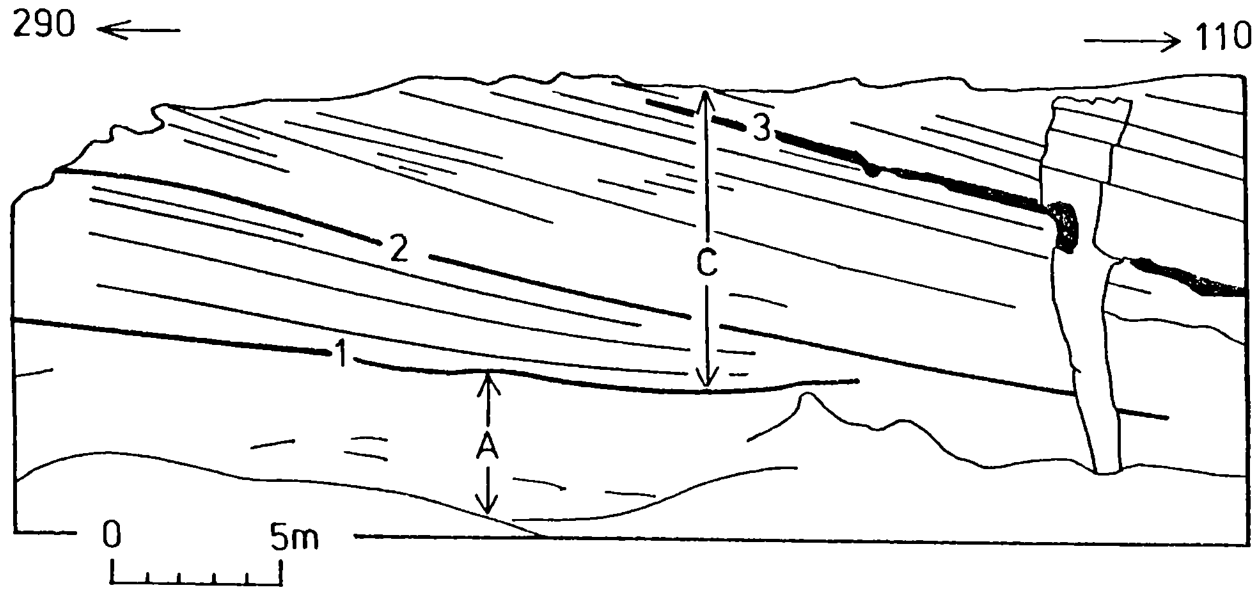
Traced sketch of photograph (Plate 73) showing individual Scour based sand bodies, A, B and C (Distributary Channels) composing the Pule Hill Grit in Pule Hill. Note the concordance of the cross-strata to the lower bounding surface of each of the three sand bodies. Erosional surface labelled 1 can be traced continuously from the N-S face of the quarry to the NW-SE face shown in Figure 48.



360
180
C
B
C
1
A
A
m
m
m
tape
0
5m
m = mud clasts

Fig. 48.

Traced sketch of photograph (Plate 77) showing sand bodies A and C and their stratification. Note erosional surface 1; internal erosional surfaces 2 and 3 and lithfacoes 12, Large Scale Cross Bedding that occur above 1 (Fig. 48 is the NW-SE face of the same sand bodies occurring in Fig. 47).



290
110
3
2
C
1
A
0
5m

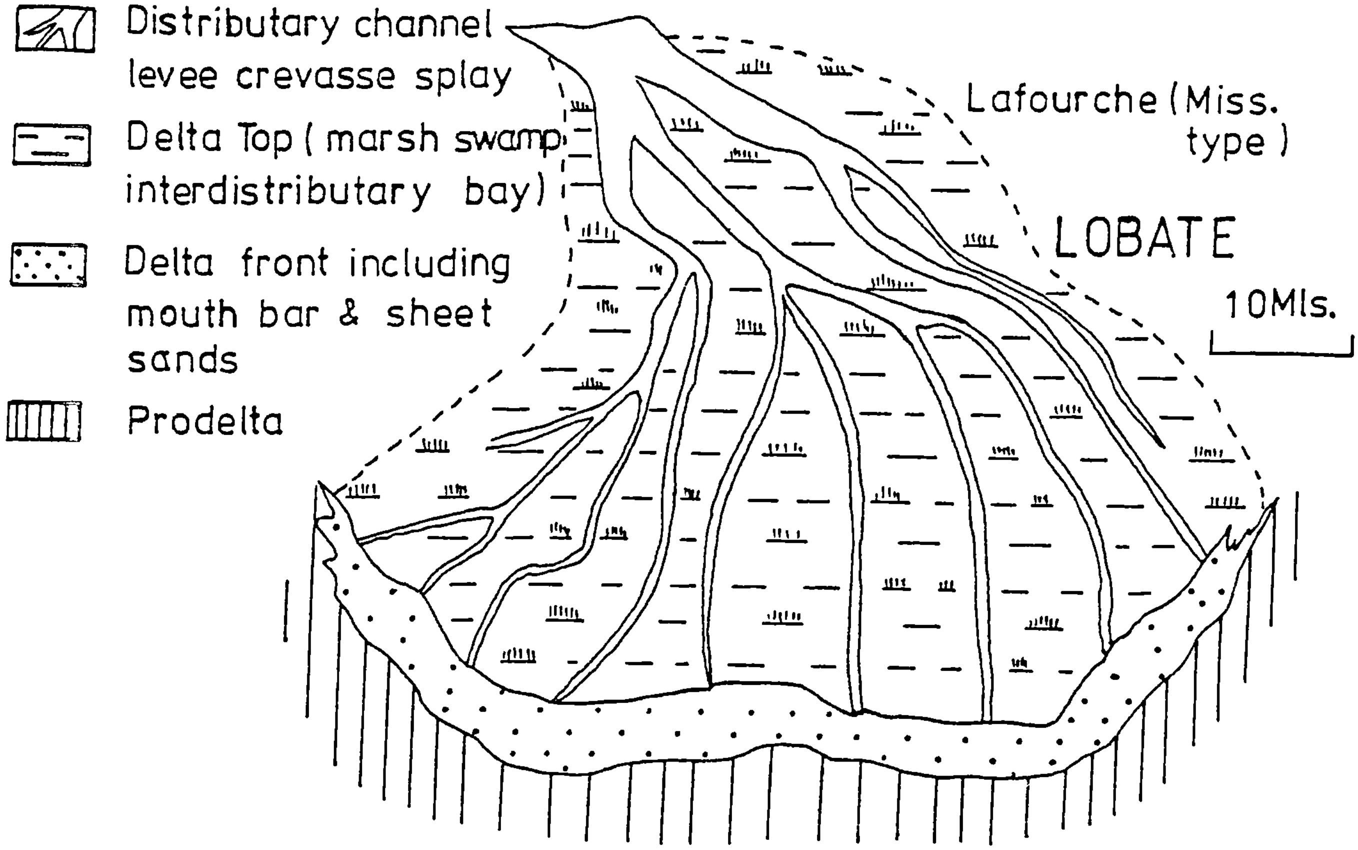

Distributary channel levee crevasse splay
Delta Top (marsh swamp interdistributary bay)
Delta front including mouth bar & sheet sands
Prodelta
Lafourche (Miss. type)
LOBATE
10Mls.

Fig. 49.

Traced sketch of photograph showing individual scour based sand bodies (channels) composing Hazel Greave Grit in Gorpley Clough.

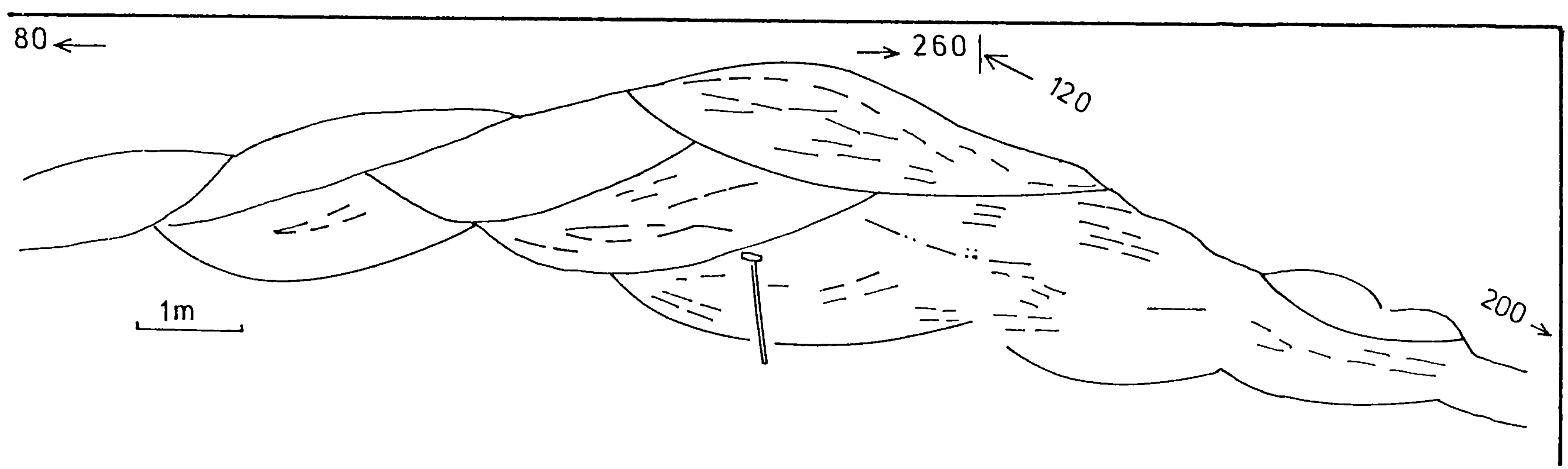

80
260
120
200
1m

Fig. 50.

Traced sketch of photograph showing individual scour based sand bodies (Channels), composing Hazel Greave Grit in Tower Hill Side.

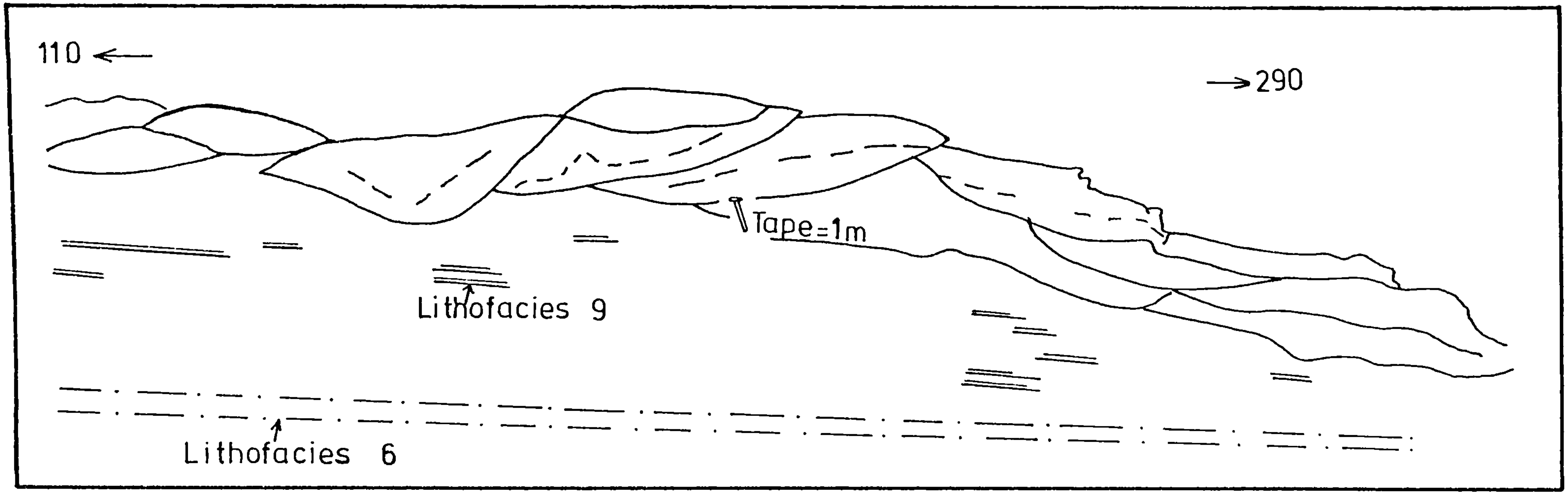

110
290
Tape=1m
Lithofacies 9
Lithofacies 6

Fig. 51.

Rose diagrams showing dip directions of Large Scale Foresets, flow directions of the Intrasets and Plant Orientation in Pule Hill Grit (Distributary Channel) at Pule Hill.(See Figures 47 and 48 for the positions of the "A", "B" and "C" Sandstones in Pule Hill (SE 032105).

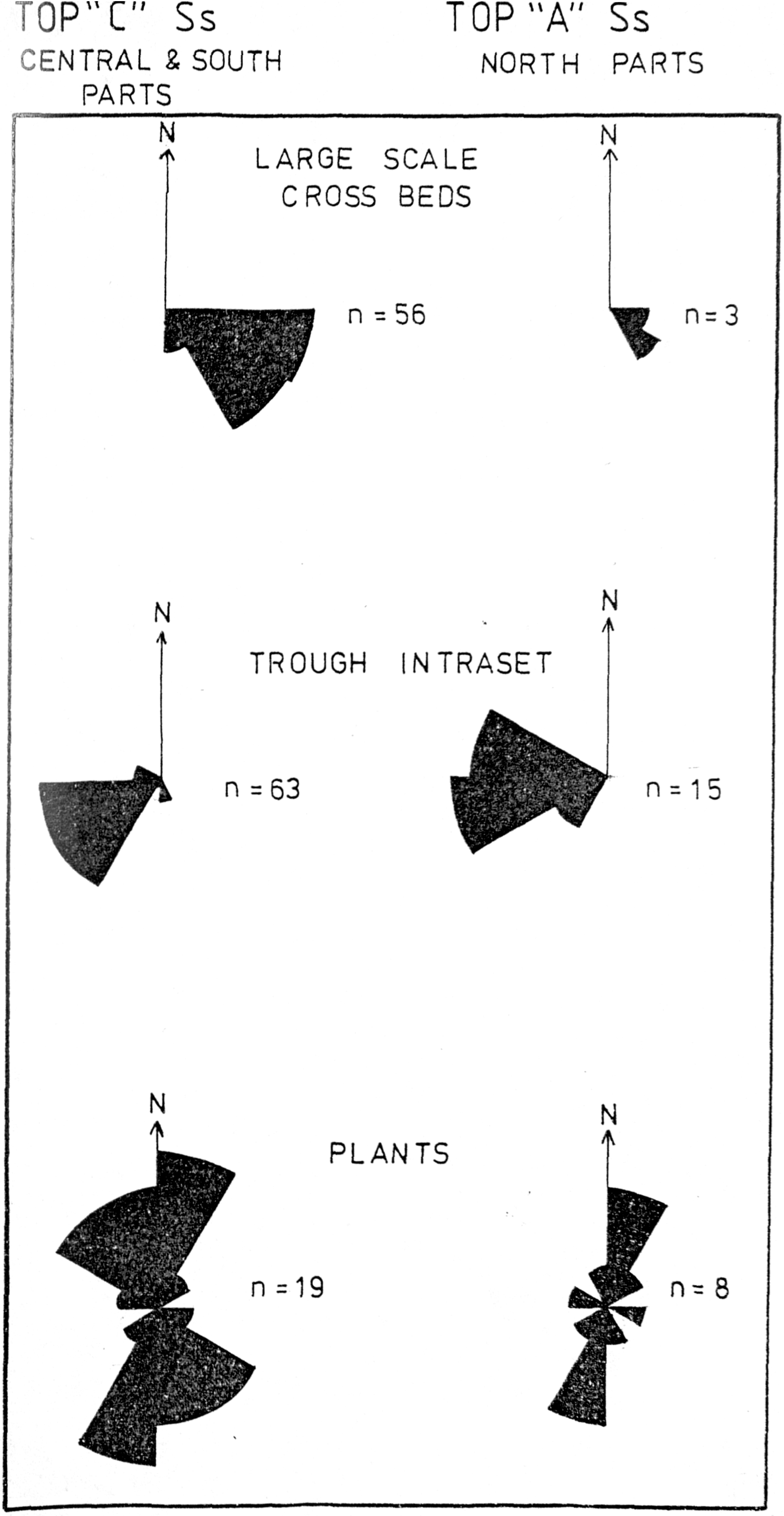

TOP "C" Ss
CENTRAL & SOUTH PARTS
TOP "A" Ss
NORTH PARTS
LARGE SCALE CROSS BEDS
N
n = 56
N
n = 3
TROUGH INTRASET
N
n = 63
N
n = 15
PLANTS
N
n = 19
N
n = 8

Fig. 52.

Vertical section of the Scotland Flags Mudstone (Prodelta with Prodelta Turbidite) at Wessenden Reservoir. This figure is the same as 0-40 levels of sequence 'b', Fig. 12 though on a larger scale in order to show more details of the section. (SE 062087).

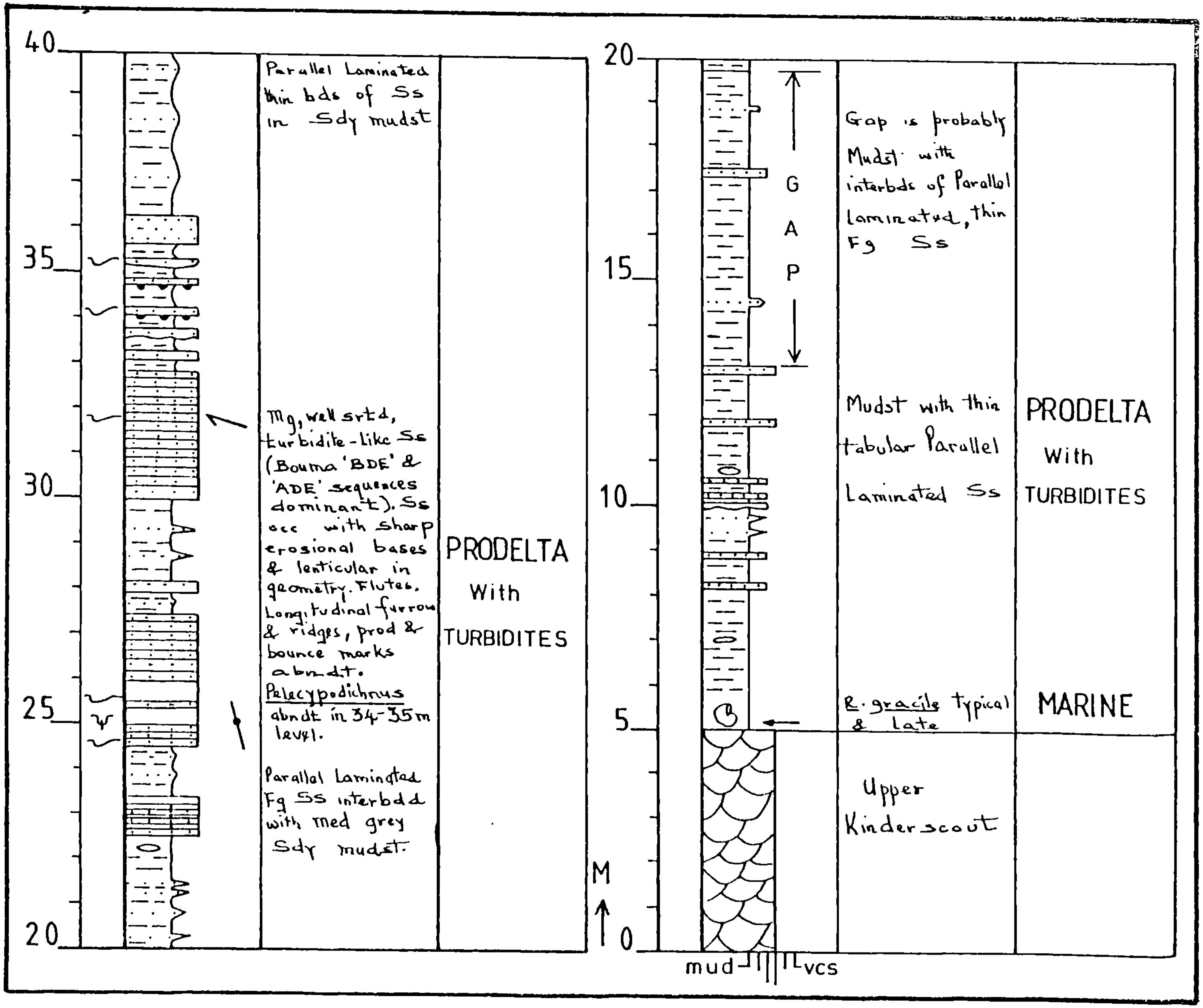

40
35
30
25
20
Parallel Laminated thin bds of Ss in Sdy mudst
Mg, well srtd, turbidite-like Ss (Bouma 'BDE' & 'ADE' sequences dominant). Ss occ with sharp erosional bases & lenticular in geometry. Flutes, Longitudinal furrow & ridges, prod & bounce marks abndt. Pelecypodichnus abndt in 34-35m level.
Parallel Laminated Fg Ss interbdd with med grey Sdy mudst.
PRODELTA With TURBIDITES
20
15
10
5
0
M
G A P
Gap is probably Mudst with interbds of Parallel laminated, thin Fg Ss
Mudst with thin tabular Parallel Laminated Ss
R. gracile typical & Late
Upper Kinderscout
PRODELTA With TURBIDITES
MARINE
mud
vcs

Fig. 53.

Vertical Section of Scotland Flags Interval in Readycon Dean (SD 993127).

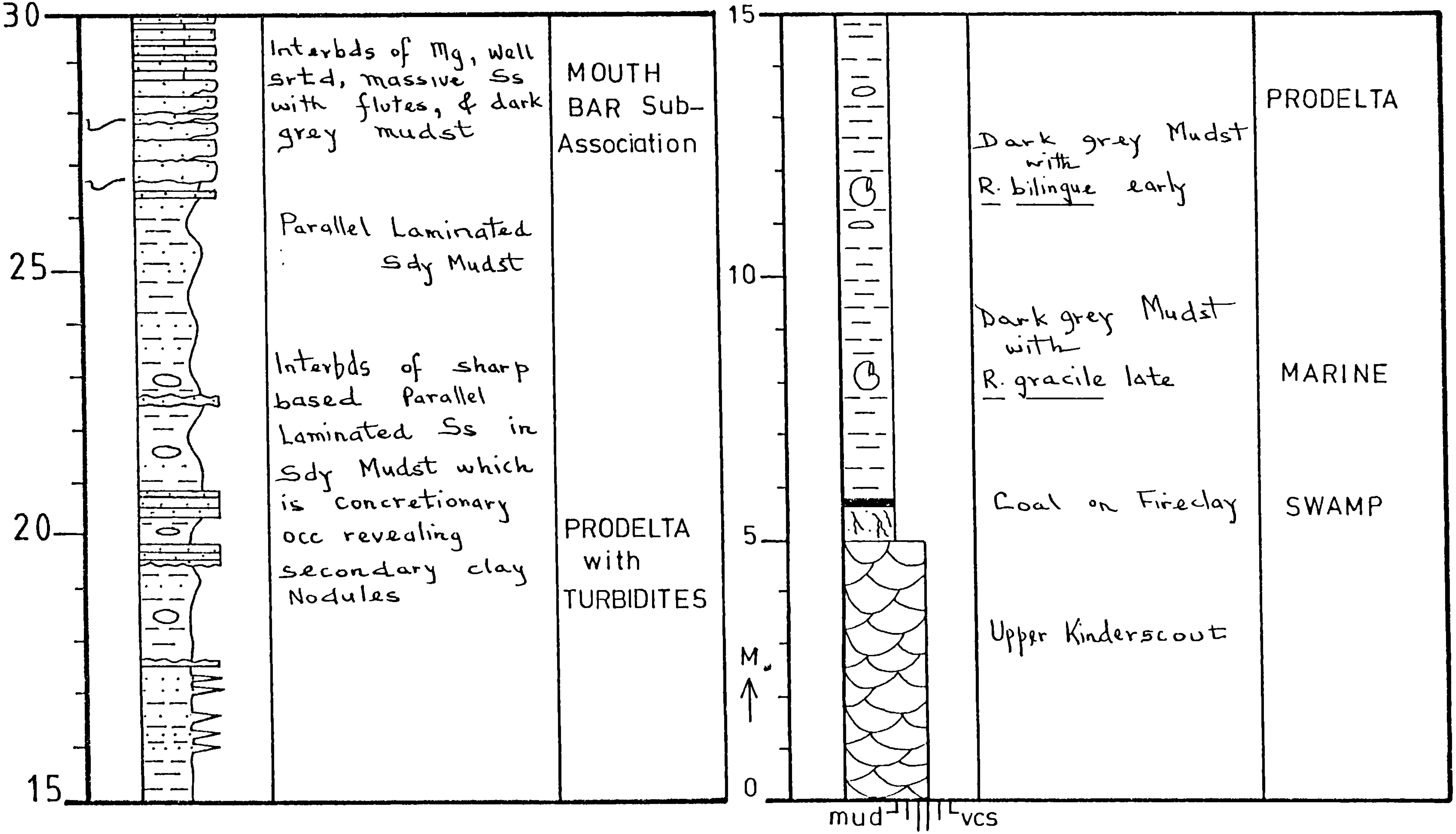
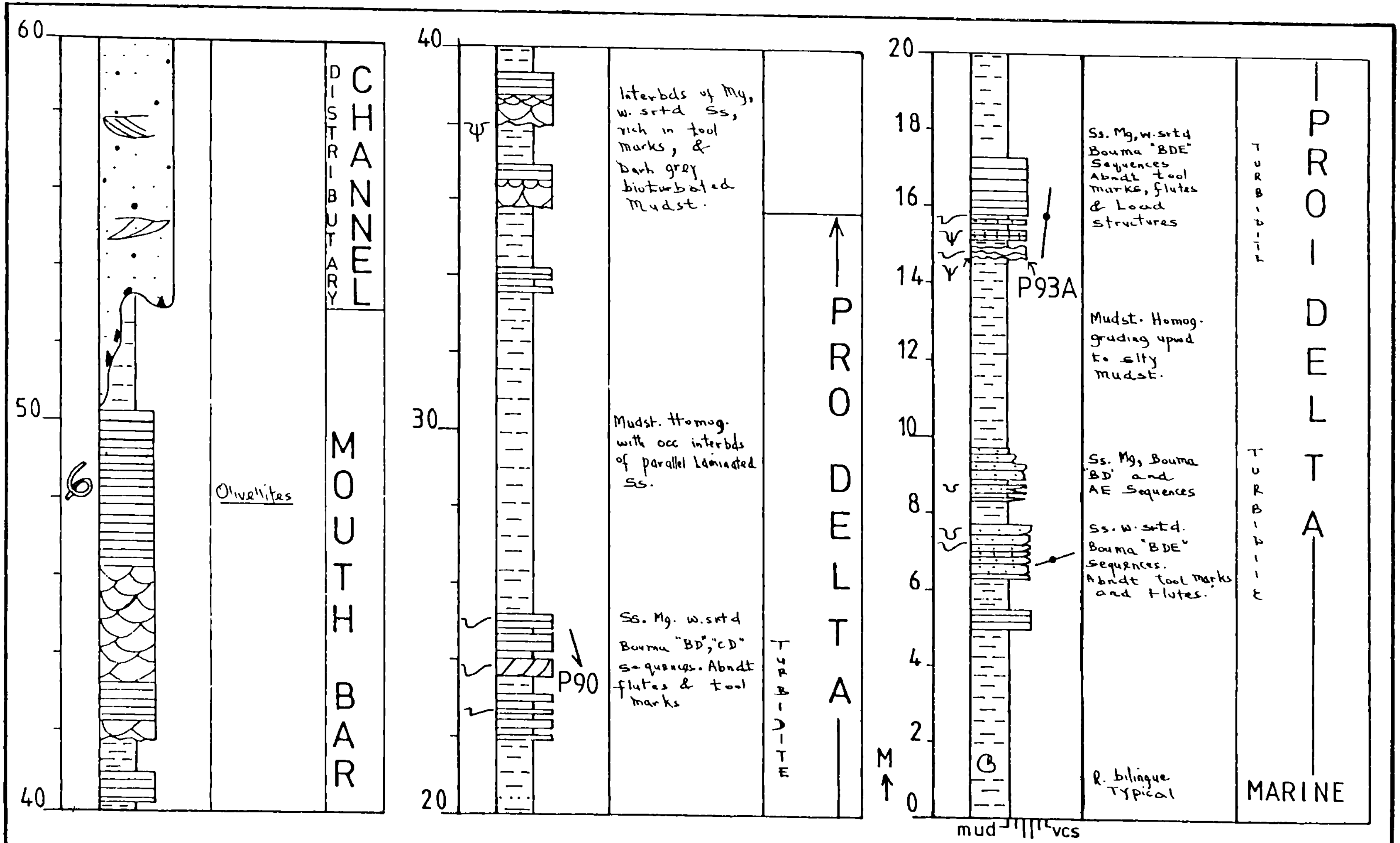

30
25
20
15
Interbds of Mg, well srtd, massive Ss with flutes, & dark grey mudst
Parallel Laminated Sdy Mudst
Interbds of sharp based Parallel Laminated Ss in Sdy Mudst which is concretionary occ revealing secondary clay Nodules
MOUTH BAR Sub-Association
PRODELTA with TURBIDITES
15
10
5
0
M.
mud
vcs
Dark grey Mudst with R. bilingue early
Dark grey Mudst with R. gracile late
Coal on Fireclay
Upper Kinderscout
PRODELTA
MARINE
SWAMP

Fig. 54.

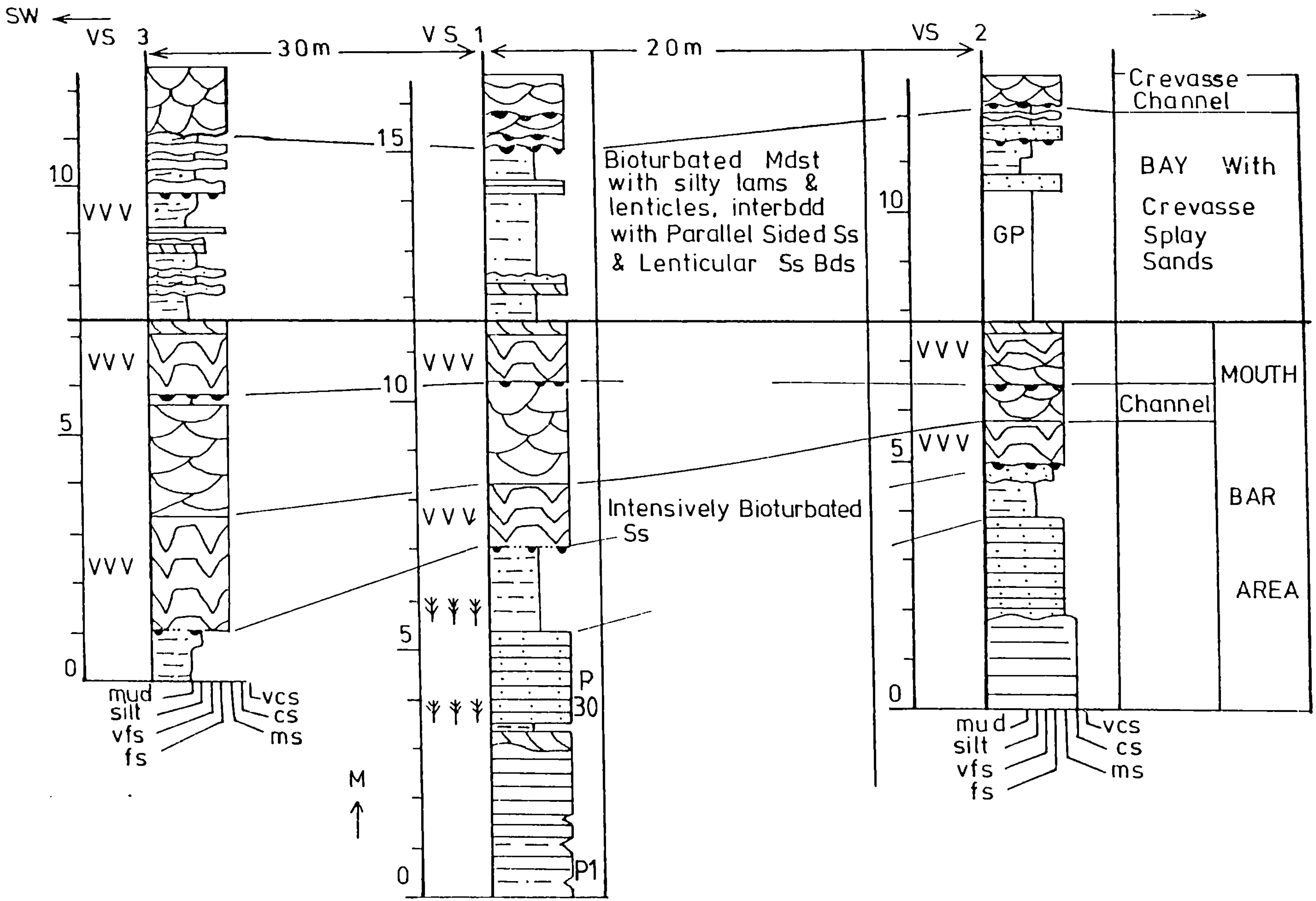
Vertical Section of the Pule Hill Mudstone (Prodelta with Prodelta turbidites) at Gorpley Clough. Figure is the same as 0-60m levels of sequence 'g', Fig. 16. but on a larger scale in order to show more details of the section (SD 915235).



FULL LEGEND AS IN FIGS 17 & 85

Fig. 55.

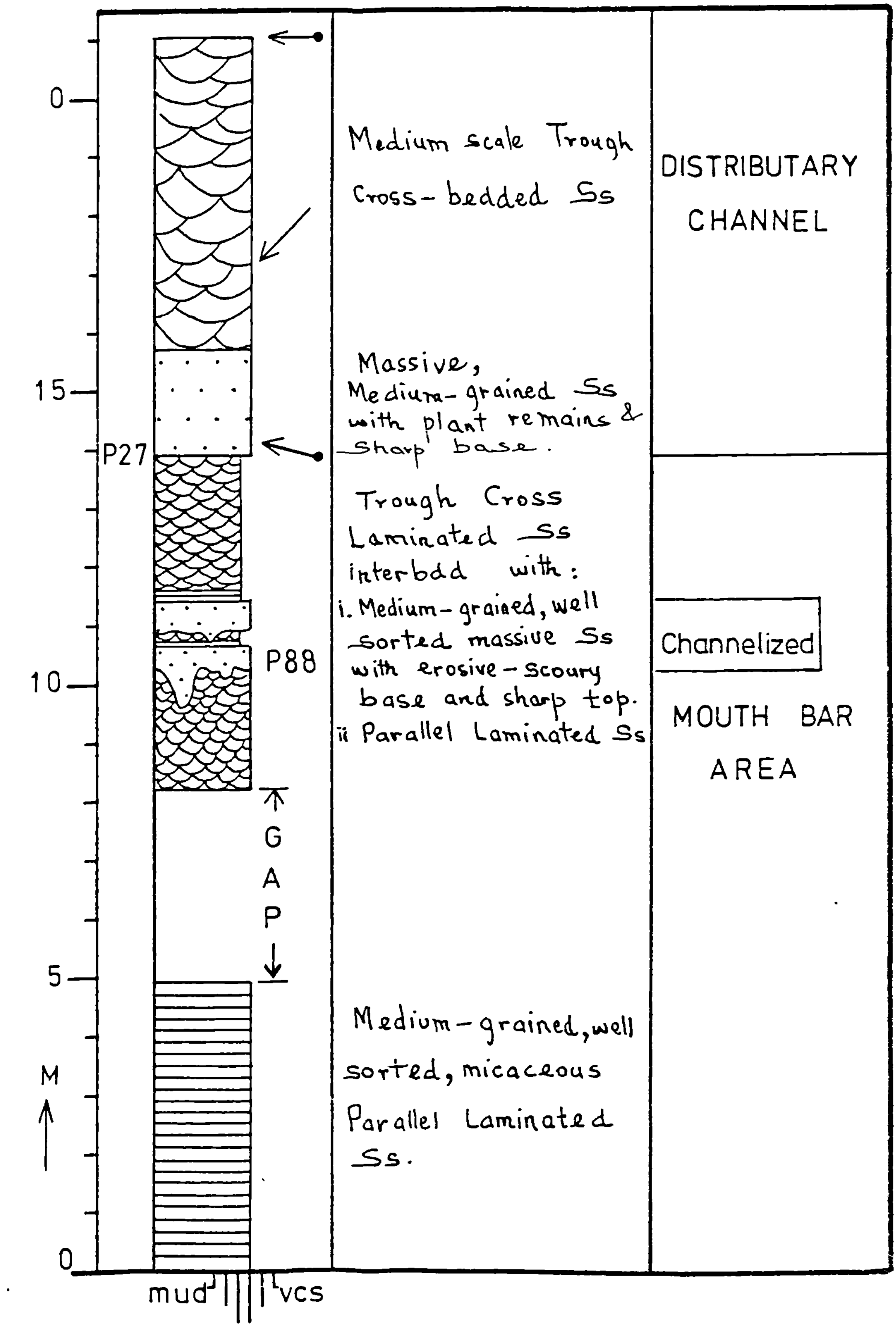
NE-SW Stratigraphical Section in Scotland Flags Sequence of Scotland Quarry (SE 033268). Note the lenticular channel sand body sandwiched by intensively bioturbated sand body. (Refer to legend opposite Fig. 16 for explanations of the notations used).



SW
VS 3
30m
VS 1
20m
VS 2
Crevasse Channel
Bioturbated Mdst with silty lams & lenticles, interbdd with Parallel Sided Ss & Lenticular Ss Bds
BAY With Crevasse Splay Sands
GP
MOUTH
Channel
BAR
AREA
Intensively Bioturbated Ss
P 30
P1
M
mud
silt
vfs
fs
vcs
cs
ms

Fig. 56.

Vertical Section of the Pule Hill Grit exposed in Heyden Road (SE 097035).



0
15
P27
10
5
M
0
mud
vcs
P88
G A P
Medium scale Trough Cross-bedded Ss
Massive, Medium-grained Ss with plant remains & sharp base.
Trough Cross Laminated Ss interbdd with:
i. Medium-grained, well sorted massive Ss with erosive-scoury base and sharp top.
ii Parallel Laminated Ss
Medium-grained, well sorted, micaceous Parallel Laminated Ss.
DISTRIBUTARY CHANNEL
Channelized
MOUTH BAR AREA

Fig. 57.

Vertical Section of Scotland Flags Interval in Ramsden Clough.

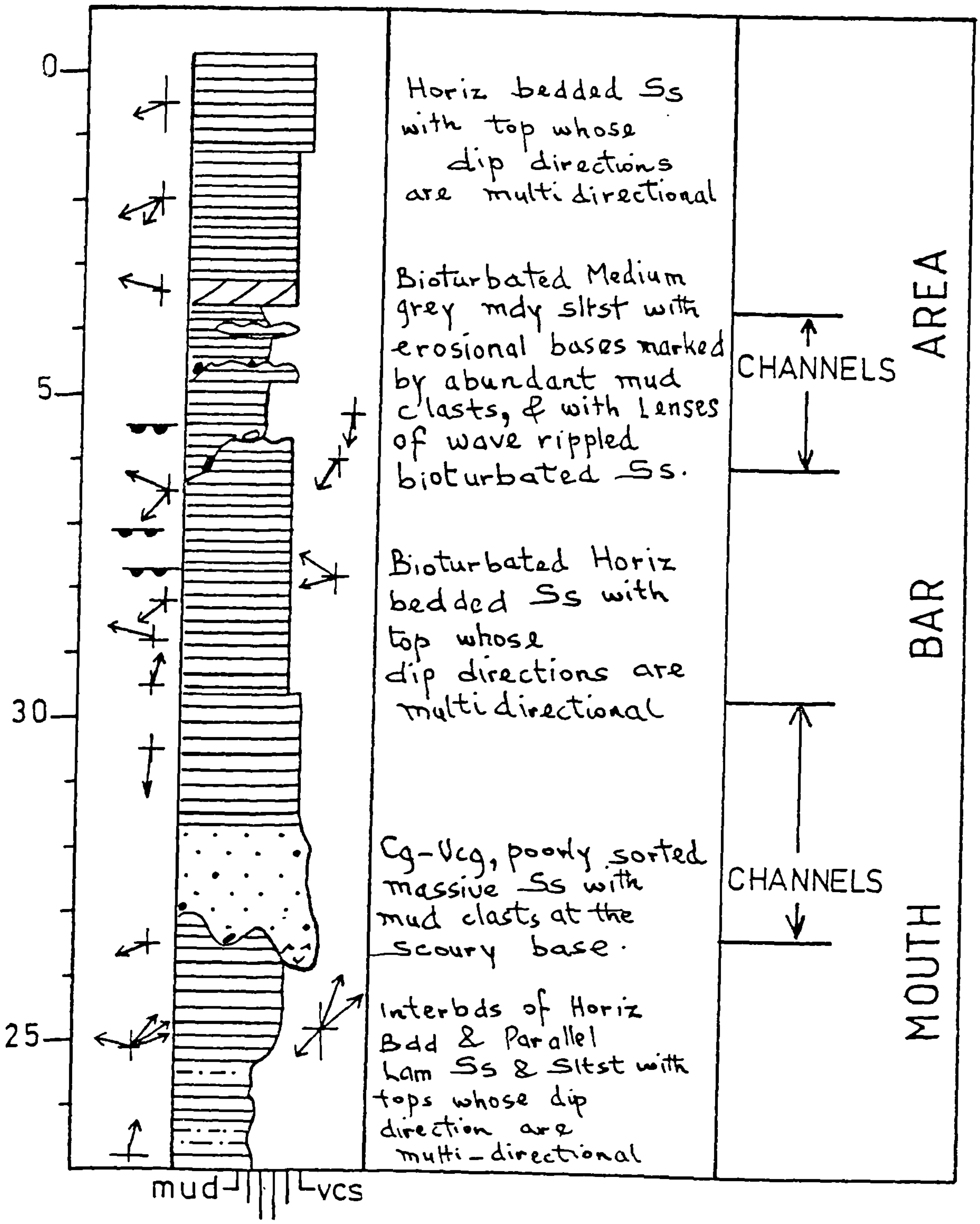
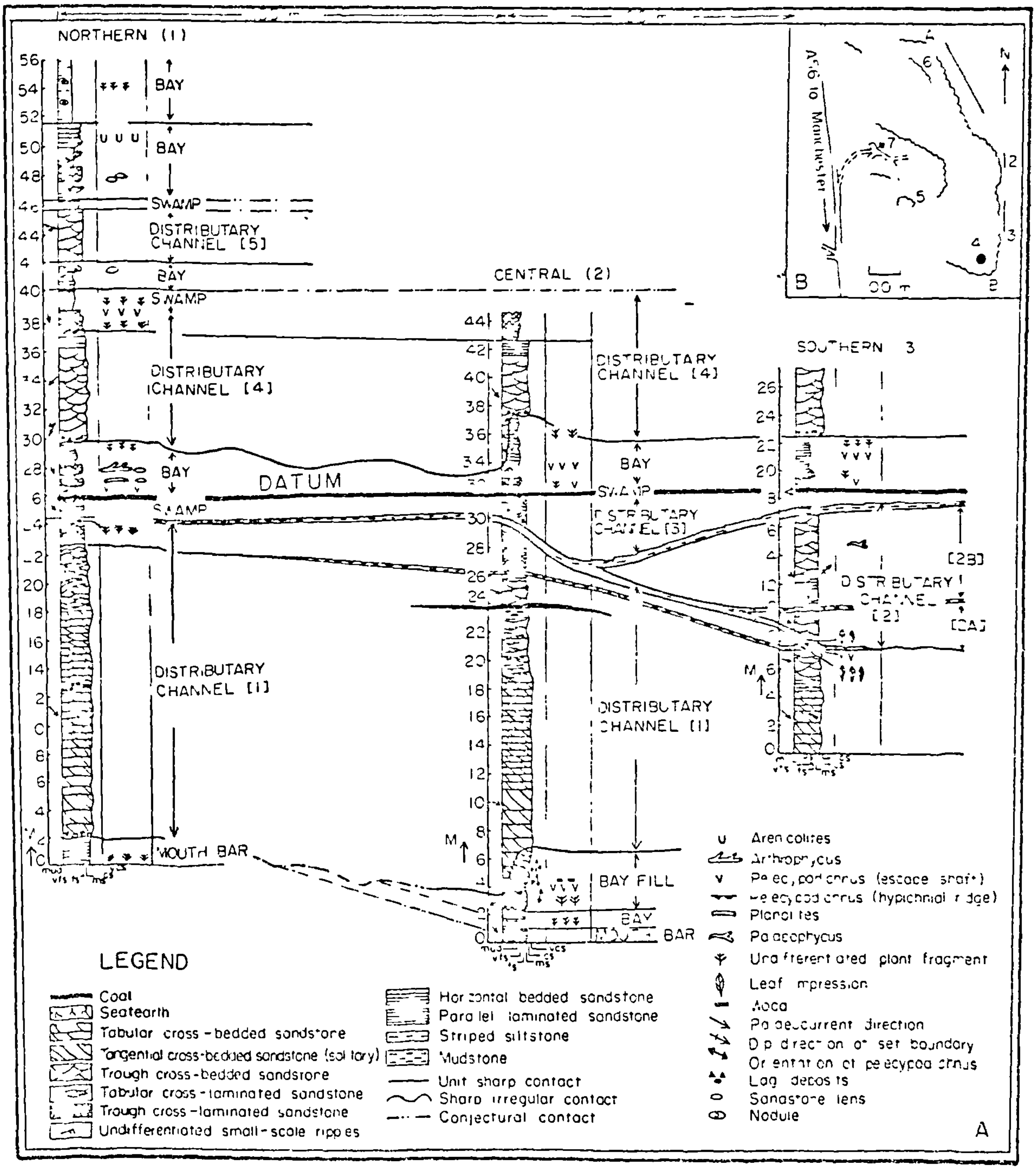

0
5
30
25
Horiz bedded Ss with top whose dip directions are multi directional
Bioturbated Medium grey mdy sltst with erosional bases marked by abundant mud clasts, & with Lenses of wave rippled bioturbated Ss.
Bioturbated Horiz bedded Ss with top whose dip directions are multi directional
Cg-Vcg, poorly sorted massive Ss with mud clasts at the scoury base.
Interbds of Horiz Bdd & Parallel Lam Ss & Sltst with tops whose dip direction are multi-directional
CHANNELS
CHANNELS
MOUTH BAR AREA
mud
vcs

Fig. 58.

Delta Model indicating typical arrangement of major components. (See page 174 of Volume 1).

Fig. 59A.

North-south stratigraphical correlation of the composition vertical sections in Fletcher Bank Quarry.(B) Plan of Fletcher Bank Quarry. A-B = prominent quarry face. 1, 2, 3 = lateral extents of northern, central and southern vertical sections respectively of (A). 4= borehole location. 5,6 = location of Plates 101B and 75 respectively. 7 = quarry office. From Okolo (1982).



NORTHERN (1)
CENTRAL (2)
DATUM
BAY
SWAMP
DISTRIBUTARY CHANNEL [5]
DISTRIBUTARY CHANNEL [4]
DISTRIBUTARY CHANNEL [1]
MOUTH BAR
BAY FILL
BAR
B
LEGEND
Coal
Seatearth
Tabular cross-bedded sandstone
Tangential cross-bedded sandstone (solitary)
Trough cross-bedded sandstone
Tabular cross-laminated sandstone
Trough cross-laminated sandstone
Undifferentiated small-scale ripples
Horizontal bedded sandstone
Parallel laminated sandstone
Striped siltstone
Mudstone
Unit sharp contact
Sharp irregular contact
Conjectural contact
Arenicolites
Arthrophycus
Leaf impression
Paleocurrent direction
Lag deposits
Nodule
A

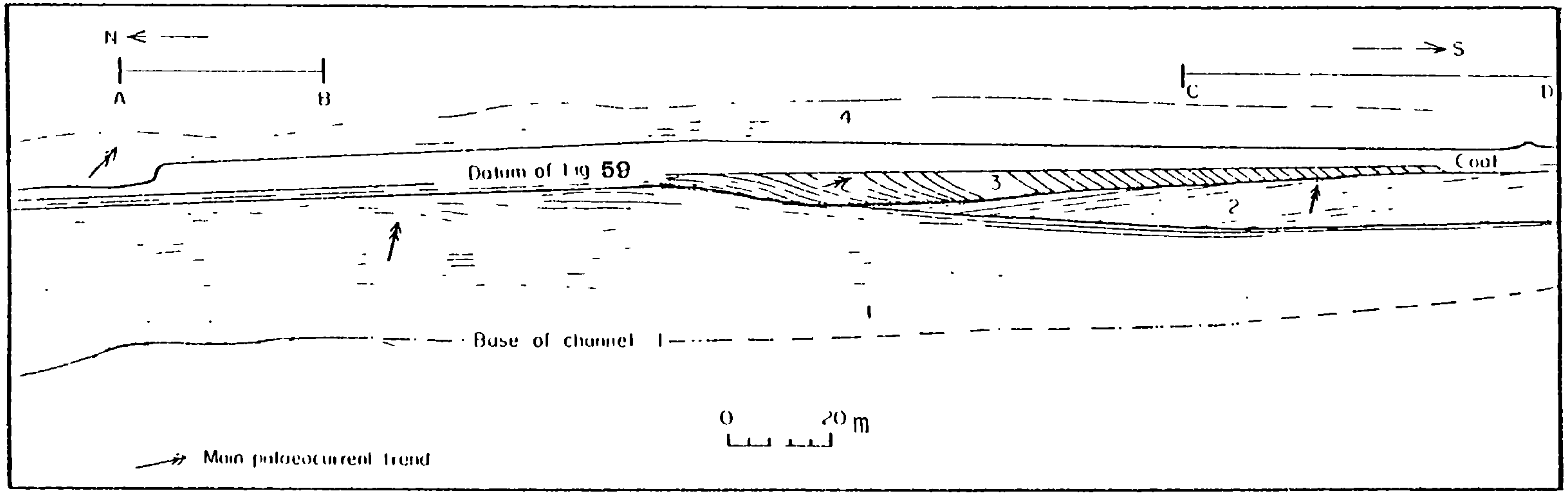


Fig. 60. Traced sketch of photograph (plate 102) illustrating the relationships between channels 1 to 4, exposed in the Central and Southern parts of Fletcher Bank Quarry (in Pule Hill Grit). (From Okolo, 1982). A - B, C - D are lateral extents of Central and Southern Vertical Sections respectively in Fig. 59A.

Fig. 61.

Alternate bar reconstruction for tangentially based foresets inclined obliquely to Fletcher Bank Channel 3 axis.

A

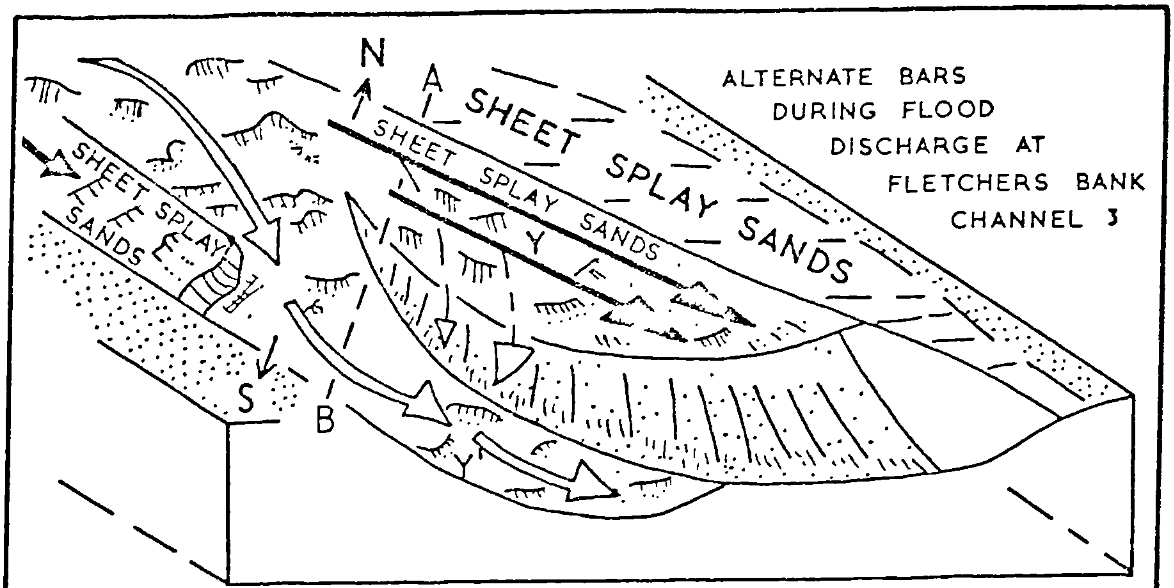


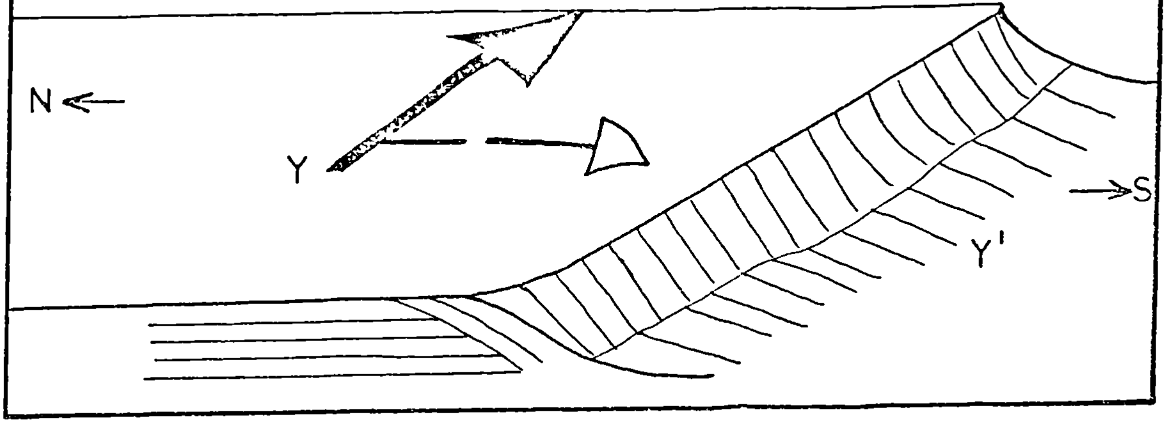
Fig 61 Alternate bar reconstruction for tangentially based foresets inclined obliquely to Fletcher Bank Channel 3 axis. Note sheet splay overbank sands (Modified from McCabe 1977, Casey 1980)

Maximum flow velocity at thalweg

Flow in the Leeside surface

Flow component at the flank of Alternate bar

A — — B Fletchers Bank Quarry face



B

Directional structures during flood stage Flow in the lower part of the Upper flow regime

Fig. 62.

Sketch diagram illustrating the fill geometry and cross-cutting relationships of Channels 2 and 3 in Fletcher Bank Quarry (Pule Hill Grit). SD 805165.

(See page 189 of Volume 1).

Fig. 63.

Palaeocurrent Histogram for Fletcher Bank Channel 3. [A] Foreset dip direction within the Channel. [B] Plants on top of Channel 3c. Ripple flow direction on top of Channel 3. (See page 189 of Vol. 1).

Fig. 64.

Model of Channel Filling in Scotland Flags at Diggley Quarry, SE 110074. (See page 190 of Volume 1).

Fig. 65.

Directional data in Scotland Flags at Diggley Quarry, SE 110074. (See pages 190 and 191 of Volume 1).

A. Flutes at base of Erosional Surface (1) of Fig. 42.

B. Foreset dip direction.

C. *Pelecypodichnus* "Bumps" Orientation.

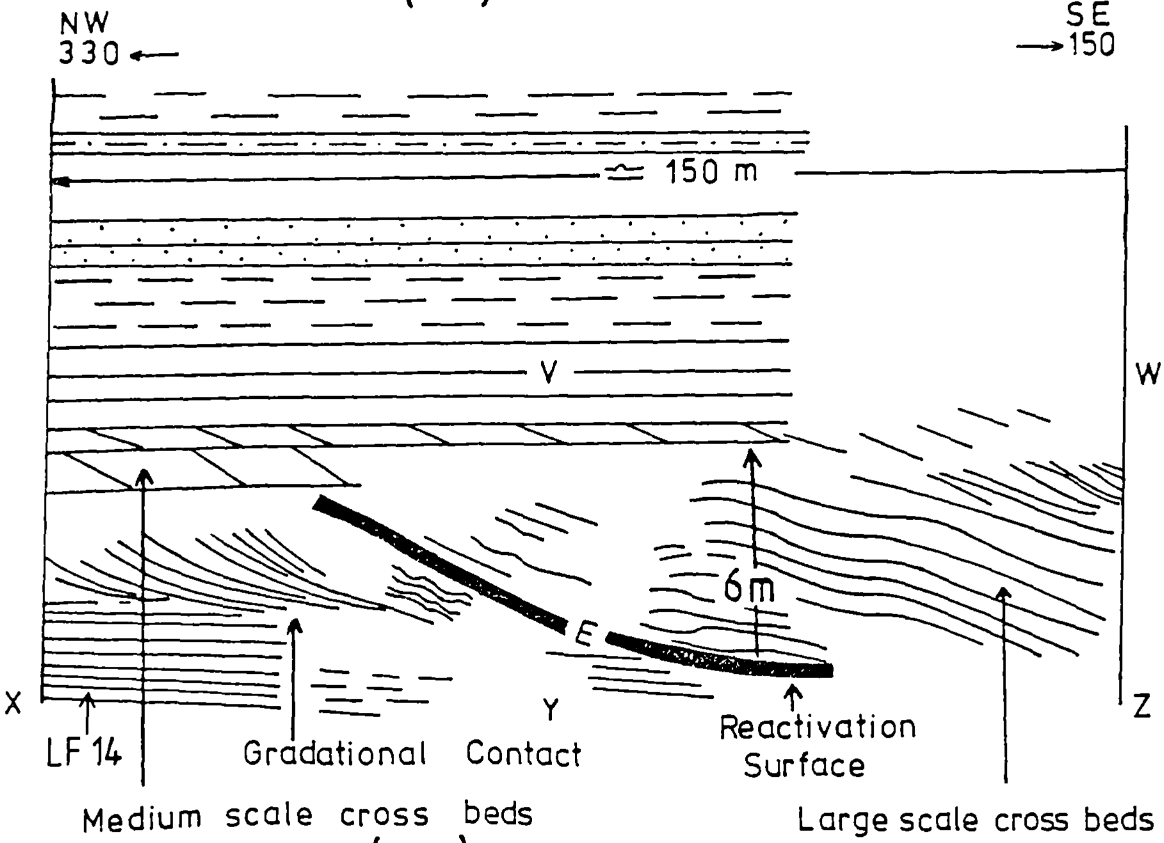
Fig. 66.

Field sketches of the sedimentary structure relationships in the Pule Hill Grit (Mouth Bar, Channel) in Ramsden Clough. 'U V Y X', 'Y W Z Y' and BB' constitute the areal coverage of Plates 60,61 and 62 respectively. (Not drawn to scale). Note the gradational contact between Lithofacies (LF) 14, Horizontal Bedded Sandstone and 12, Large Scale Cross Bedding.

Fig. 67.

Rose diagram of the direction of dip of the set boundaries at Fletcher Bank Channel 2(Pule Hill Grit SD 805165). (See page 193 of Volume 1).

(a)


NW
330
SE
150
≃ 150 m
V
W
6m
E
X
Y
Z
LF 14
Gradational Contact
Reactivation Surface
Medium scale cross beds
Large scale cross beds

(a')

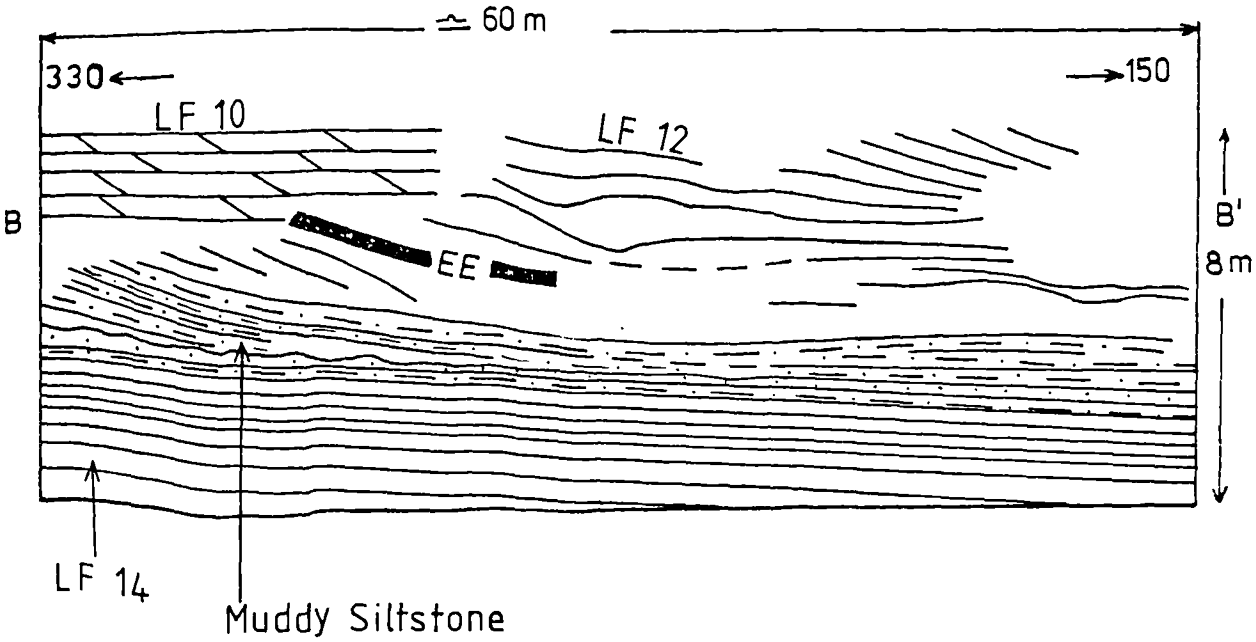

≃ 60 m
330
150
LF 10
LF 12
B
B'
8m
EE
LF 14
Muddy Siltstone

Fig. 68.

Vertical Section of the Pule Hill Grit Sequence.

Figure is the same as 75.2-90m levels of sequence 'd' of Fig. 12 but of a larger scale in order to show more details of the section.

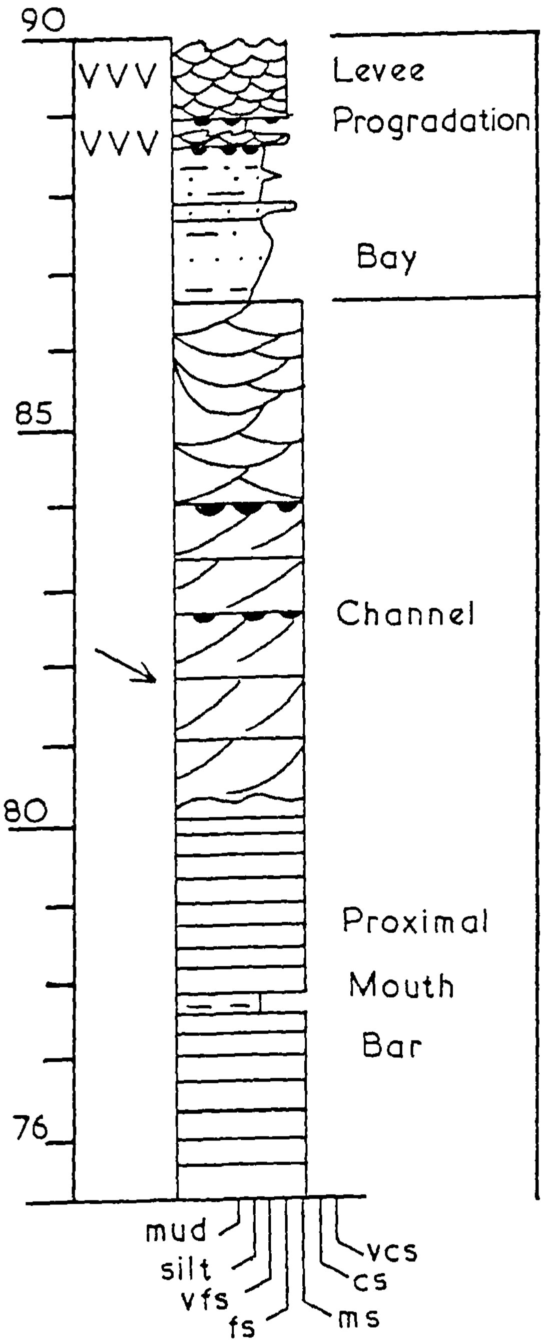
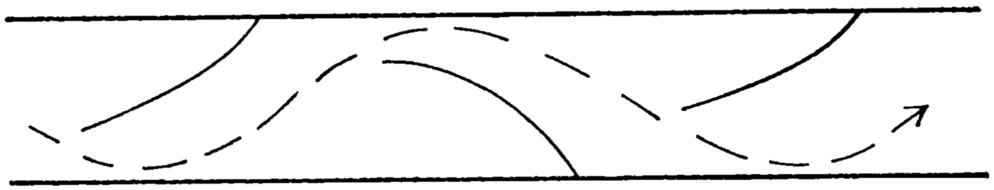

90
VVV
VVV
85
80
76
Levee
Progradation
Bay
Channel
Proximal
Mouth
Bar
mud
silt
vfs
fs
ms
cs
vcs

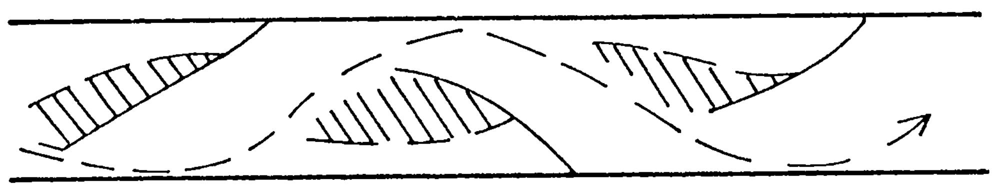
Fig. 69.

Mechanisms for the formation of Large Scale Cross Bedding within Fluviatile Channels.



A AT High Stage

B During falling stage with less water in the Channel the thalweg has a smaller wavelength & alternate bars are eroded



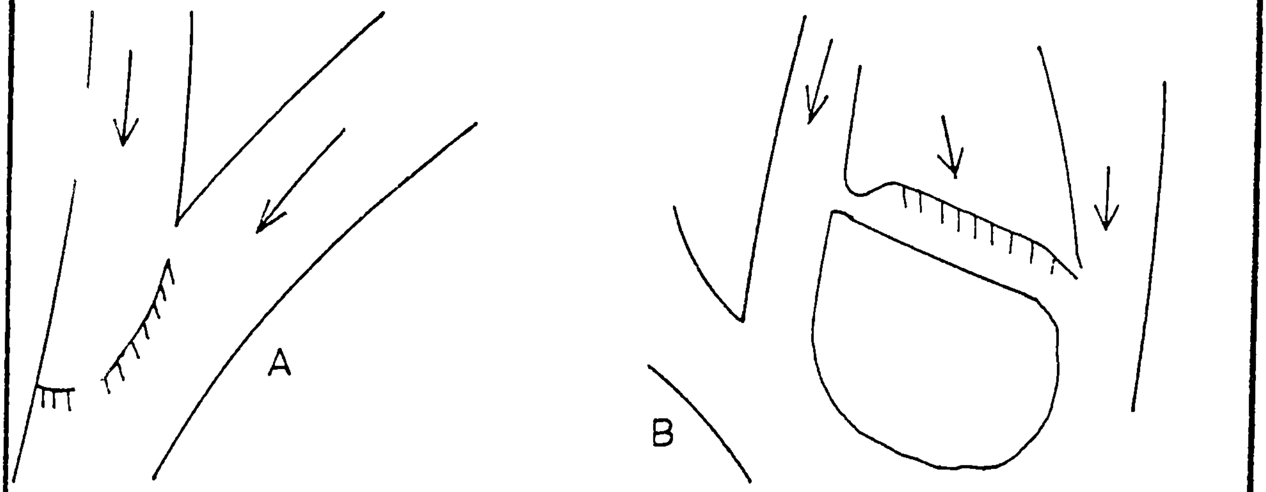
C During the suceeding High Stage, the bars are reactivated

Fig. 70.

Coset of Medium Scale and Large Scale Cross Beds in the Pule Hill Grit (Distributary Channel) at Hanging Stone Quarry (SE 044200), Ripponden (See page 197 of Volume 1).

Fig. 71.

Plan view of a straight channel with alternate bars.



A CHANNEL CONFLUENCE DELTA Can occur when a tribu ry with a high bedload enters a large relatively slow moving river

B CHANNEL INFILL DELTA Abandoned river may be filled w th a classical Gilbert type delta

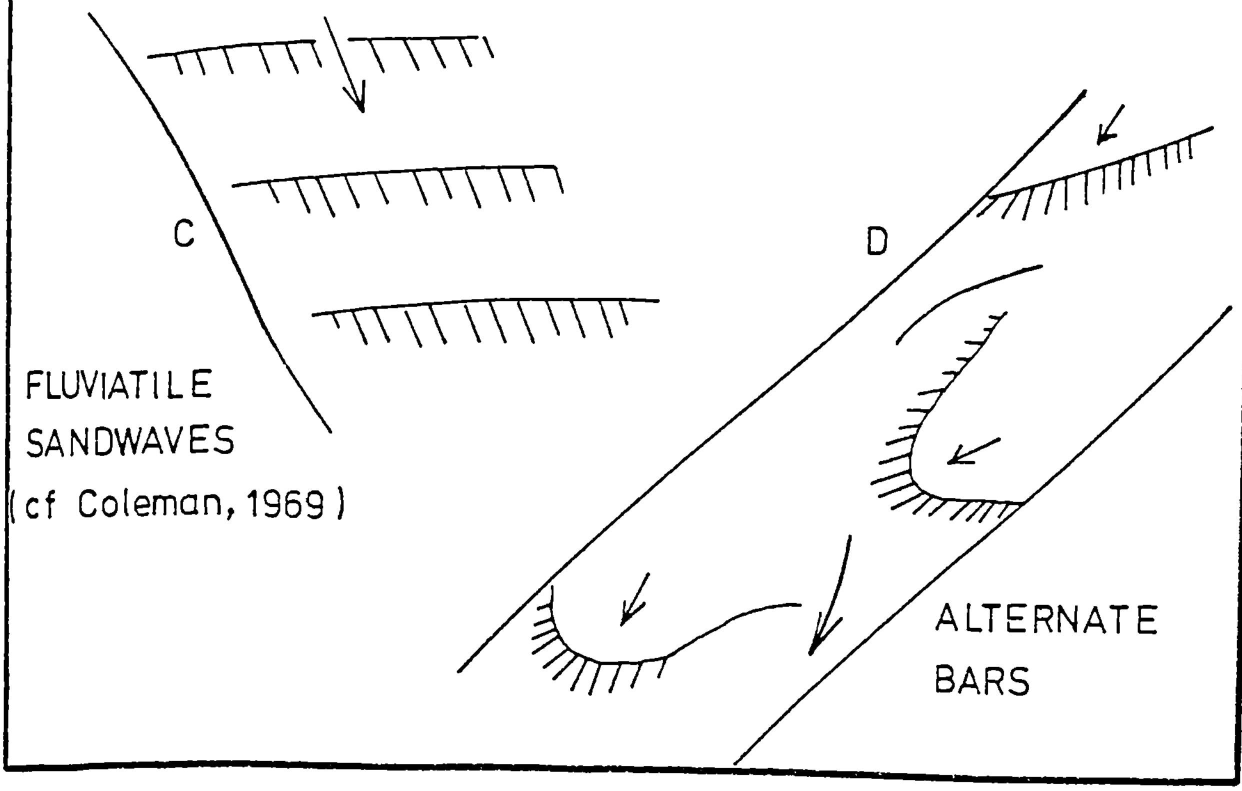


Fig. 72.

Types of Foresets in Lithofacies 12, Large Scale Cross Beds and possible types of separation eddy responsible.

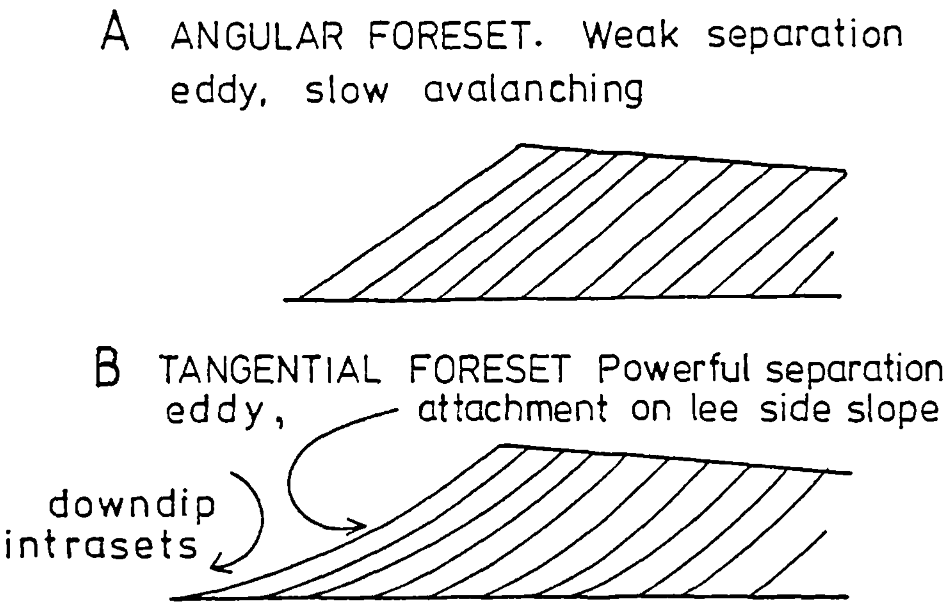

A ANGULAR FORESET. Weak separation eddy, slow avalanching
B TANGENTIAL FORESET Powerful separation eddy, attachment on lee side slope
downdip intrasets

Fig. 73.

Genesis of the low angle foresets, concave upwards foresets and internal erosion surfaces in large scale cross bedding in Diggley Quarry (modified from Collinson, 1970b).

1. Low angle foresets are produced - due to weak separation eddy.

2. Supply of sediments reduced, and because of lowering of water level advance of slip face halts, and promotes currents parallel to the side of bar, capable of depositing a laterally accreted increment.

3. Rising water stage may reactivate the cross bedded set and cause it to bury the falling stage features. The strongly developed separation eddy gives asymptotic foresets.

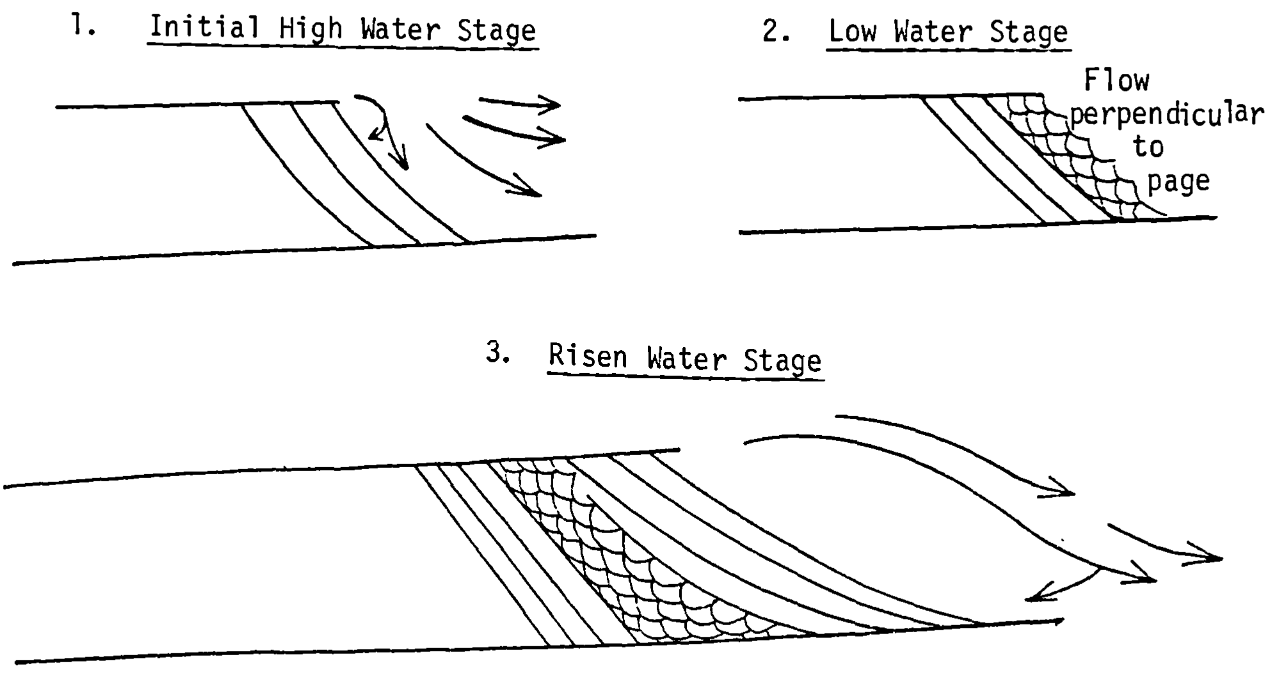
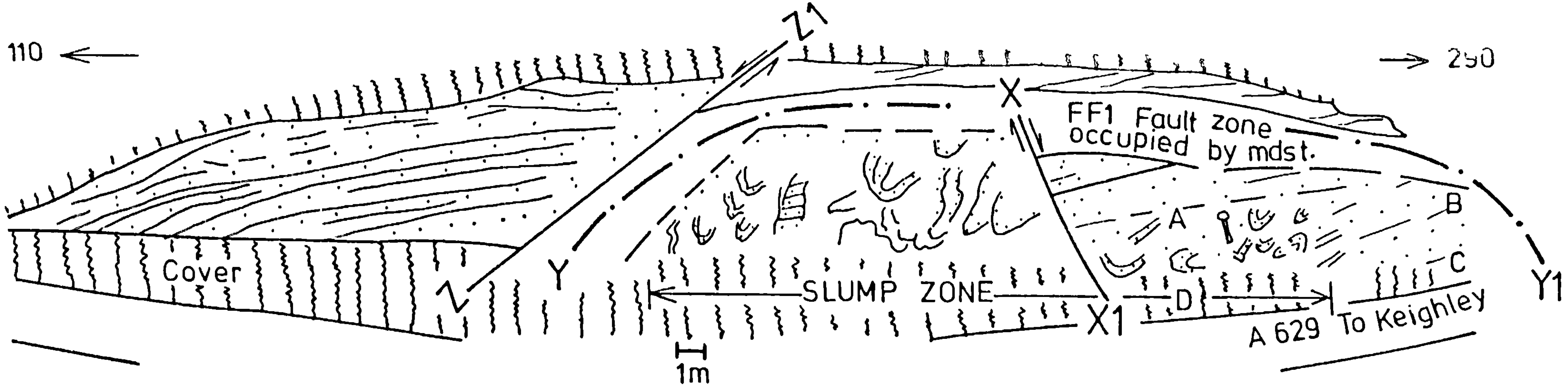


Fig. 74.

Traced sketch of photograph (Plate 109) of NW-SE face of Hazel Greave Grit (Distributary Channel)in Wicking Crag Quarry showing Faults YY', XX', ZZ' and the slumped zone which occurs at the downthrown side of the major fault YY'. A B C D marks the areal extent covered by Figure 75.

Fig. 75.

Traced sketch of photograph (Plate 110) showing details of the NW parts of the slump zone. Note small faults (F), parallel stratified laminae (p), undulating laminae (UL) often twisted, balls (b) *and their* encircling laminae. Note also the different orientations of the balls.


110
250
Z1
X
FF1 Fault zone
occupied by mdst.
A
B
C
D
Y1
Cover
Z
Y
SLUMP ZONE
X1
1m
A 629
To Keighley

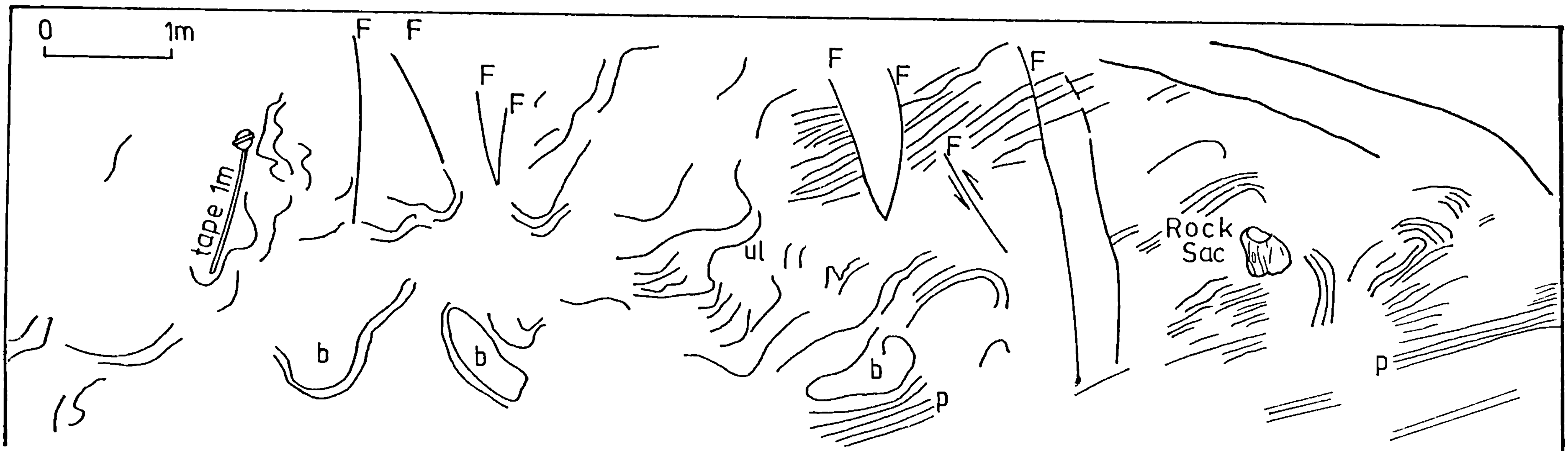
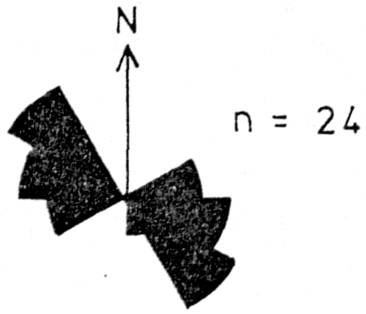

0
1m
F
tape 1m
b
ul
Rock
Sac
p

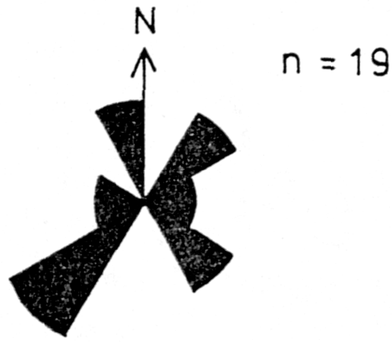
Fig. 76.

Azimuthal plot of the orientation of folds in the slumped Hazel Greave Grit (Distributary Channel) in Wicking Crag, SE 052372. (See Figs. 74 and 75 for the slump).

FOLD AXIS ORIENTATION



AXIAL PLANE DIP DIRECTION



TROUGHS IN SCOUR BASED SAND BODIES

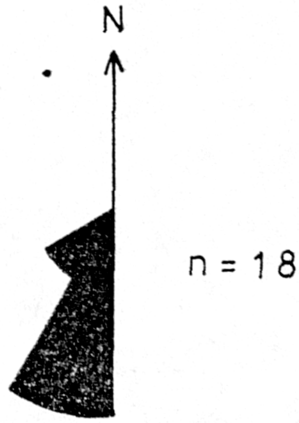


Fig. 77.

Detailed vertical section of the Scotland Flags sequence at Foster Clough Quarry 5 (SE 021273).

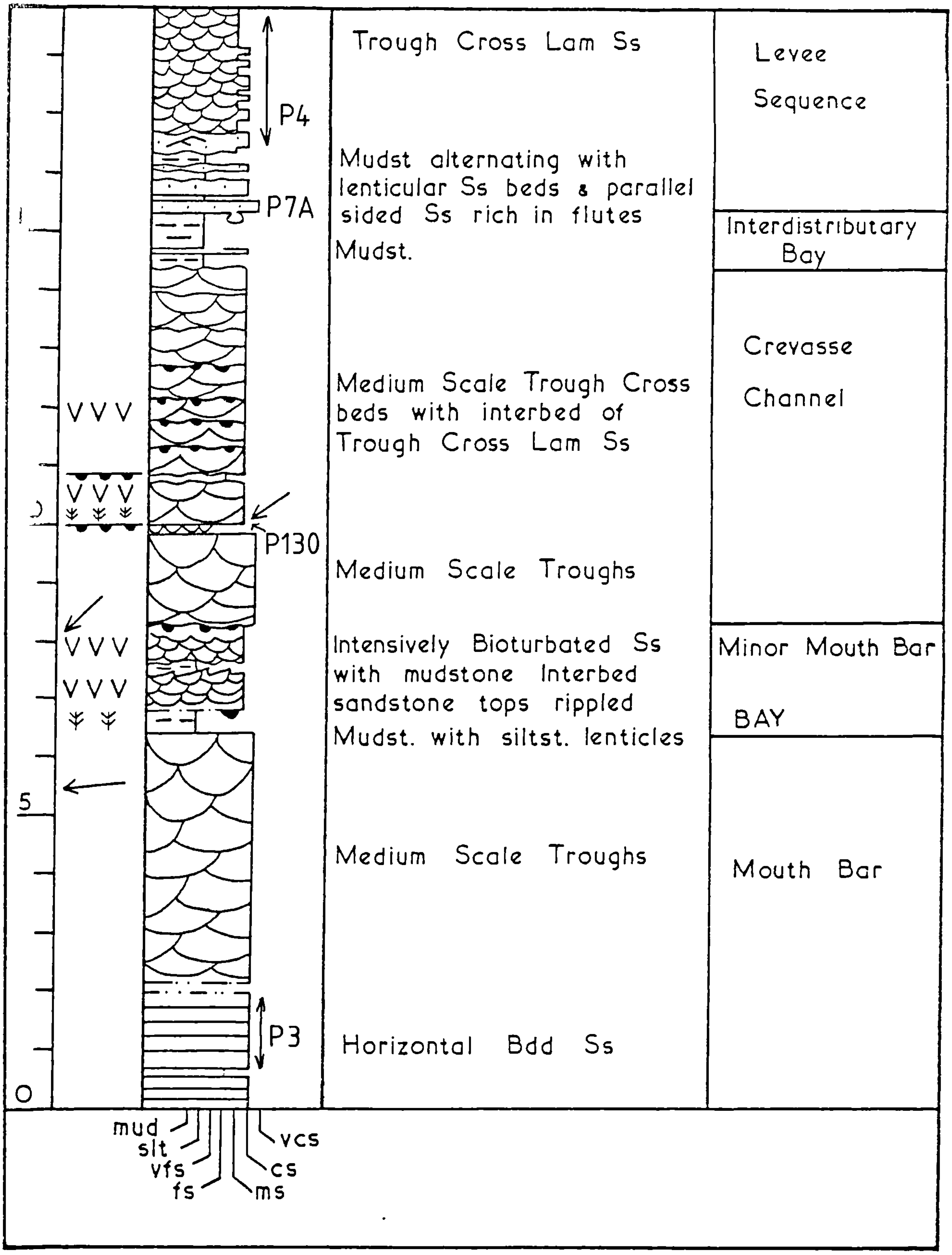


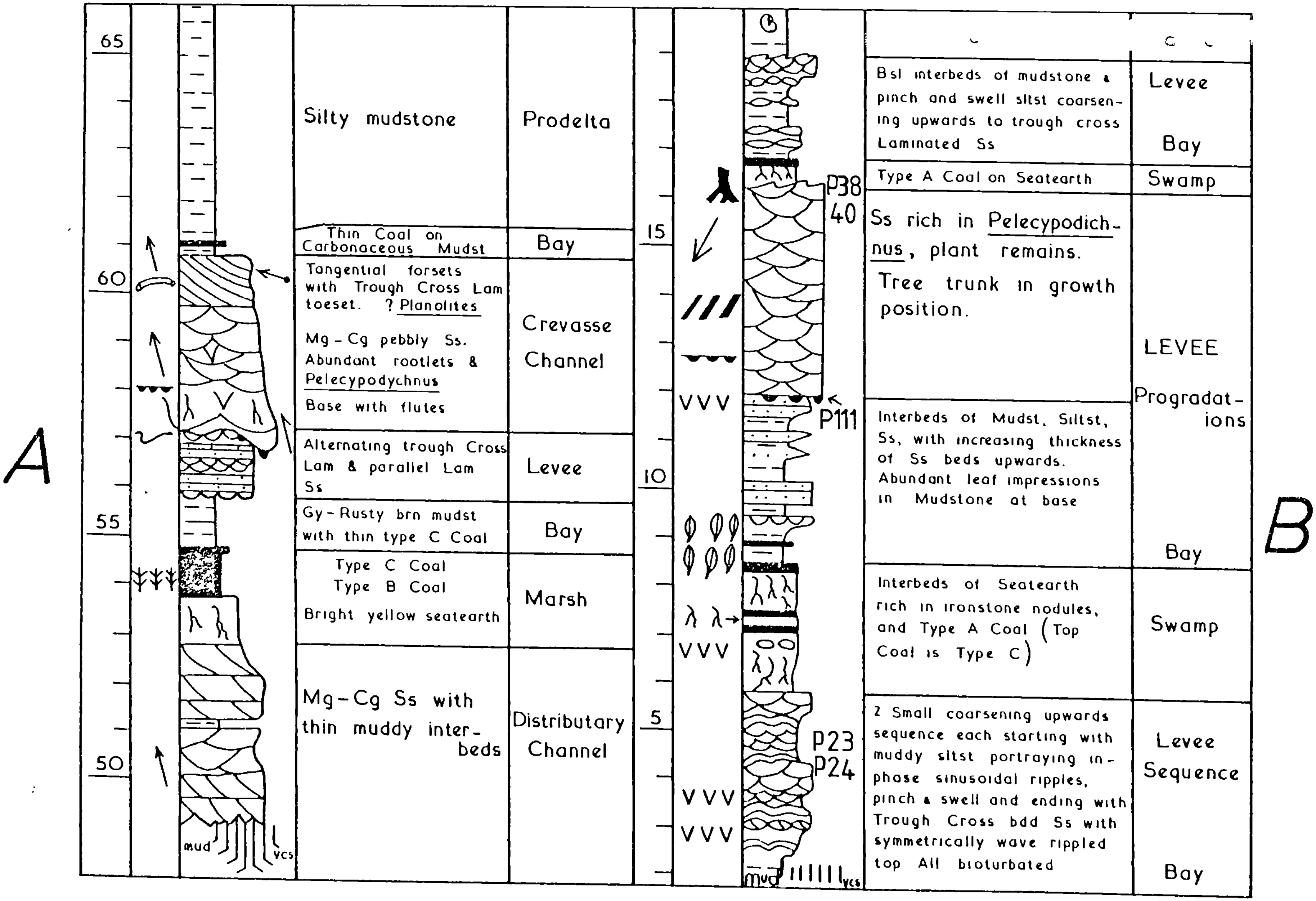
Fig 77 Foster Clough Quarry 5

Fig. 78A.

Vertical Section of the Upper parts of the Pule Hill Grit in Cowloughton Clough. (This Figure is the enlarged upper part of 'e' sequence, Fig. 17).

Fig. 78B.

Vertical Section of the Upper parts of the Pule Hill Grit in Harper Clough (This Figure is the enlarged lower parts of 'b' sequence, Fig. 17).



A
B
65
60
55
50
mud
vcs
Silty mudstone
Prodelta
Thin Coal on Carbonaceous Mudst
Bay
Tangential forsets with Trough Cross Lam toeset. ? Planolites
Mg-Cg pebbly Ss. Abundant rootlets & Pelecypodychnus
Base with flutes
Crevasse Channel
Alternating trough Cross Lam & parallel Lam Ss
Levee
Gy-Rusty brn mudst with thin type C Coal
Bay
Type C Coal
Type B Coal
Bright yellow seatearth
Marsh
Mg-Cg Ss with thin muddy inter-beds
Distributary Channel
15
10
5
P38
40
P111
P23
P24
mud
vcs
Bsl interbeds of mudstone & pinch and swell sltst coarsening upwards to trough cross Laminated Ss
Levee
Bay
Type A Coal on Seatearth
Swamp
Ss rich in Pelecypodichnus, plant remains.
Tree trunk in growth position.
LEVEE
Progradations
Interbeds of Mudst, Siltst, Ss, with increasing thickness of Ss beds upwards. Abundant leaf impressions in Mudstone at base
Bay
Interbeds of Seatearth rich in ironstone nodules, and Type A Coal (Top Coal is Type C)
Swamp
2 Small coarsening upwards sequence each starting with muddy sltst portraying in-phase sinusoidal ripples, pinch & swell and ending with Trough Cross bdd Ss with symmetrically wave rippled top All bioturbated
Levee Sequence
Bay

Fig. 79.

Detailed vertical section in the Distributary Channel - , and Interdistributary Complex Associations of the Pule Hill Grit Sequence in Buckden Clough (SD 789188).

BUCKDEN CLOUGH (Lower Part of VS "d" in fig 16)

Inset (from Elliot 1974) portrays model of Infill of Bay represented by this Section: Compare ABCD & A'B'C'D', X & X'

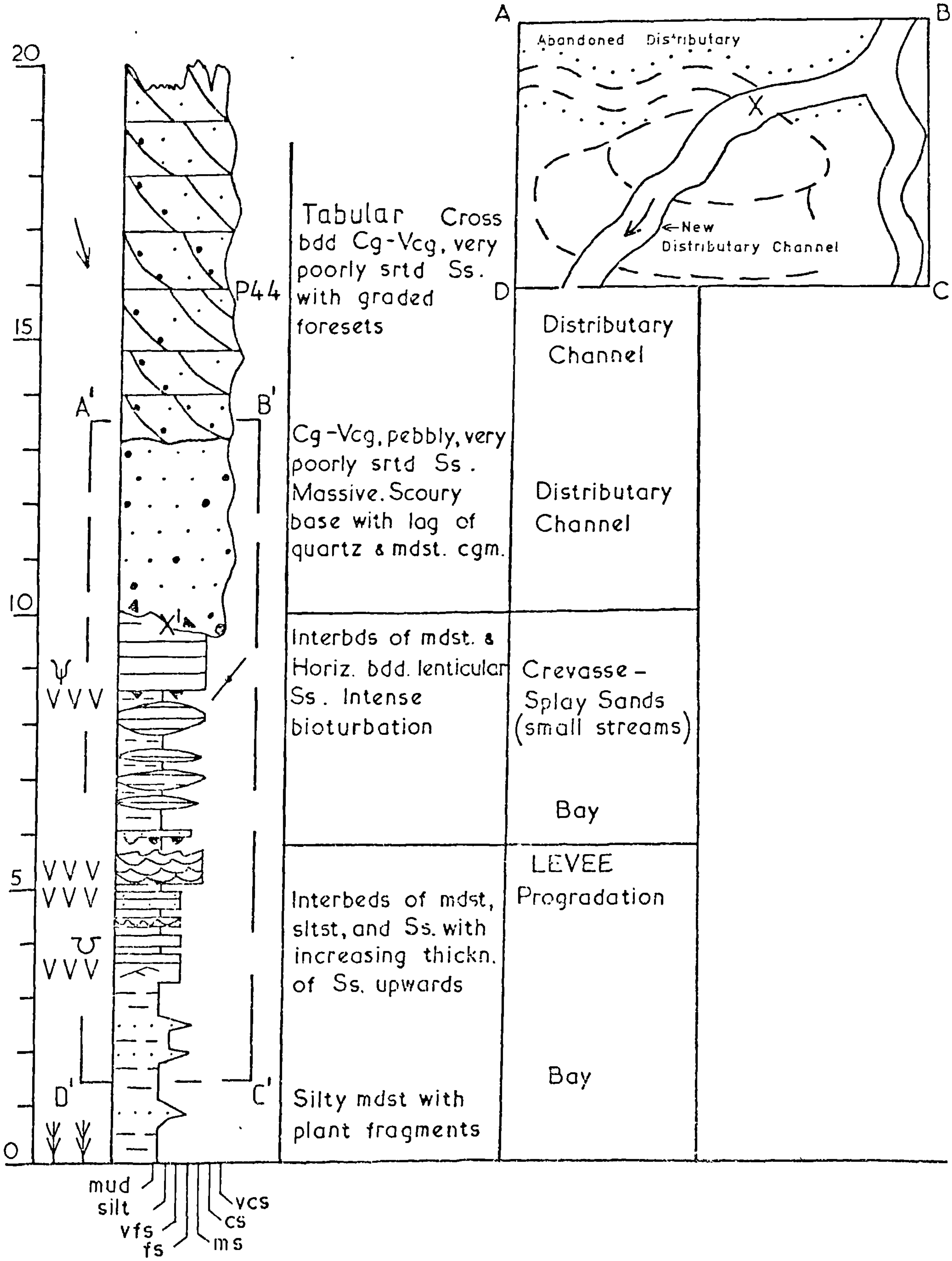
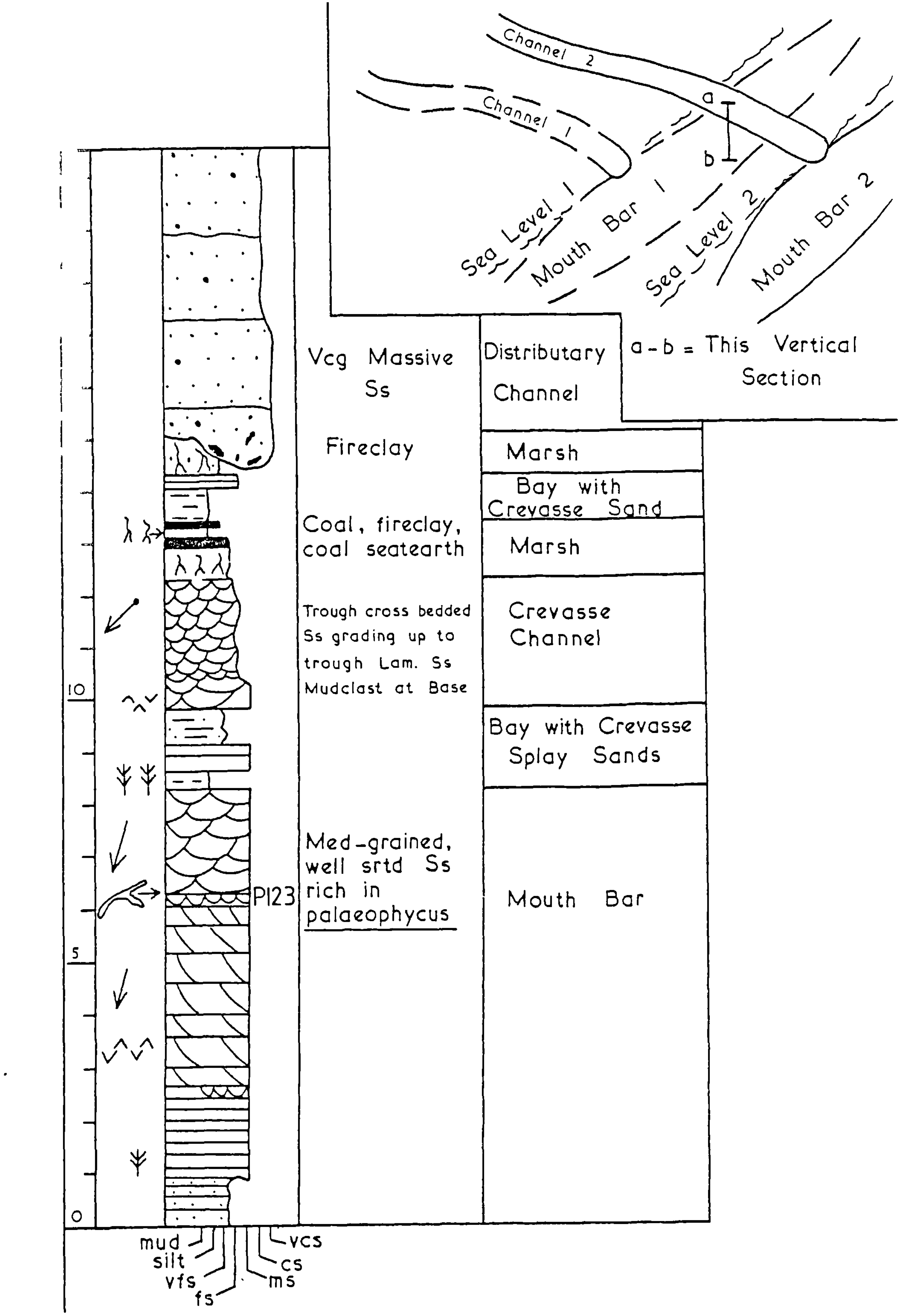


Fig. 80.

Detailed Vertical Section of the Hazel Greave Grit sequence at Scout End. The proposed model for the generation of this Grit's sequence is shown in the inset map, where the Vertical Section a-b of the inset is thought to represent the Vertical Section Fig. 80 (SD 942189).



Channel 2
Channel 1
a
b
Sea Level 1
Mouth Bar 1
Sea Level 2
Mouth Bar 2
a - b = This Vertical Section
Vcg Massive Ss
Distributary Channel
Fireclay
Marsh
Bay with Crevasse Sand
Coal, fireclay, coal seatearth
Marsh
Trough cross bedded Ss grading up to trough Lam. Ss Mudclast at Base
Crevasse Channel
Bay with Crevasse Splay Sands
Med-grained, well srtd Ss rich in palaeophycus
P123
Mouth Bar
10
5
0
mud
silt
vfs
fs
ms
cs
vcs

Fig. 81.

Vertical Section of the Pule Hill Grit at Holmbridge Woodhouse Quarry (SE 129064), near Holmfirth.

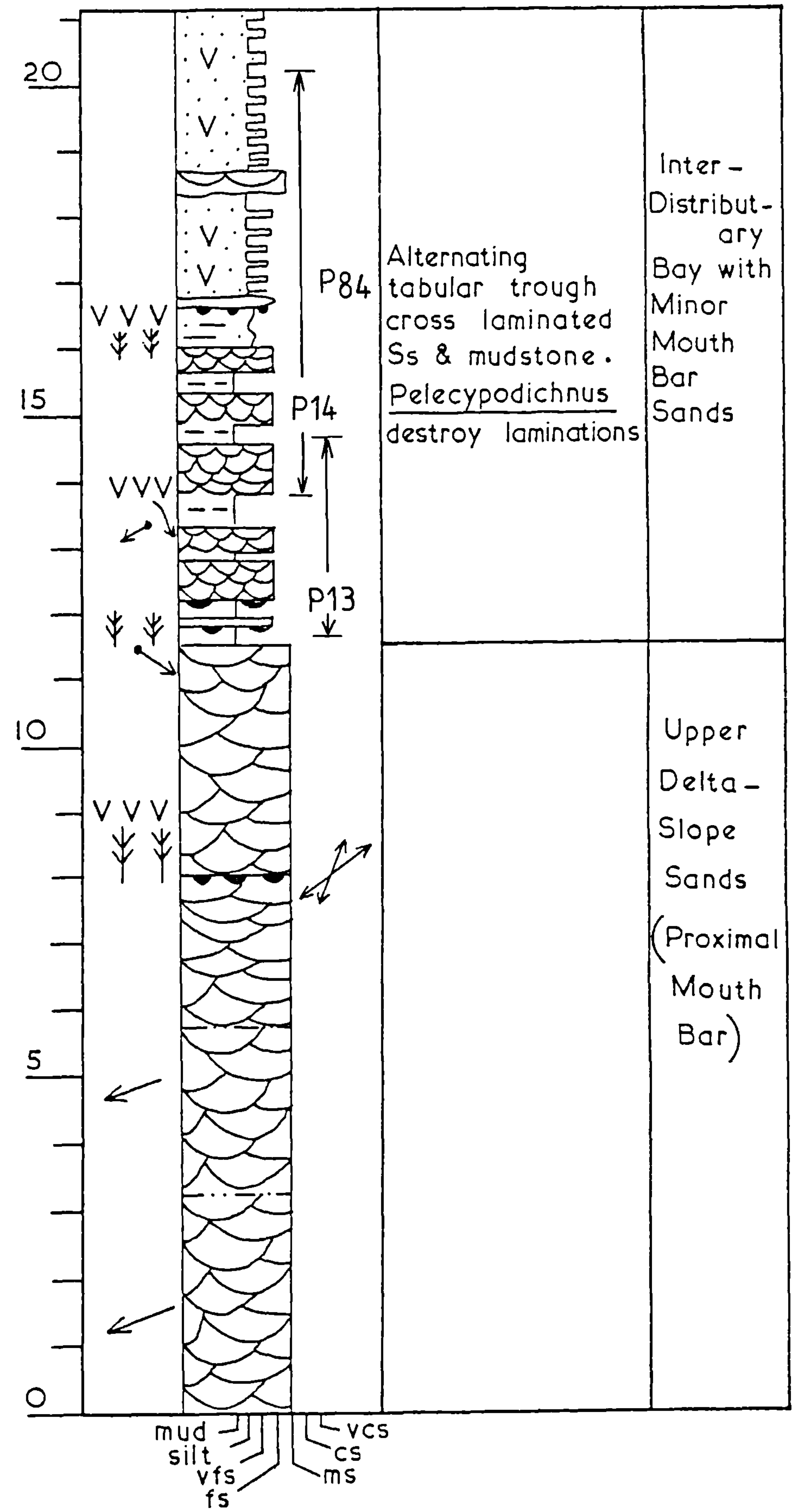
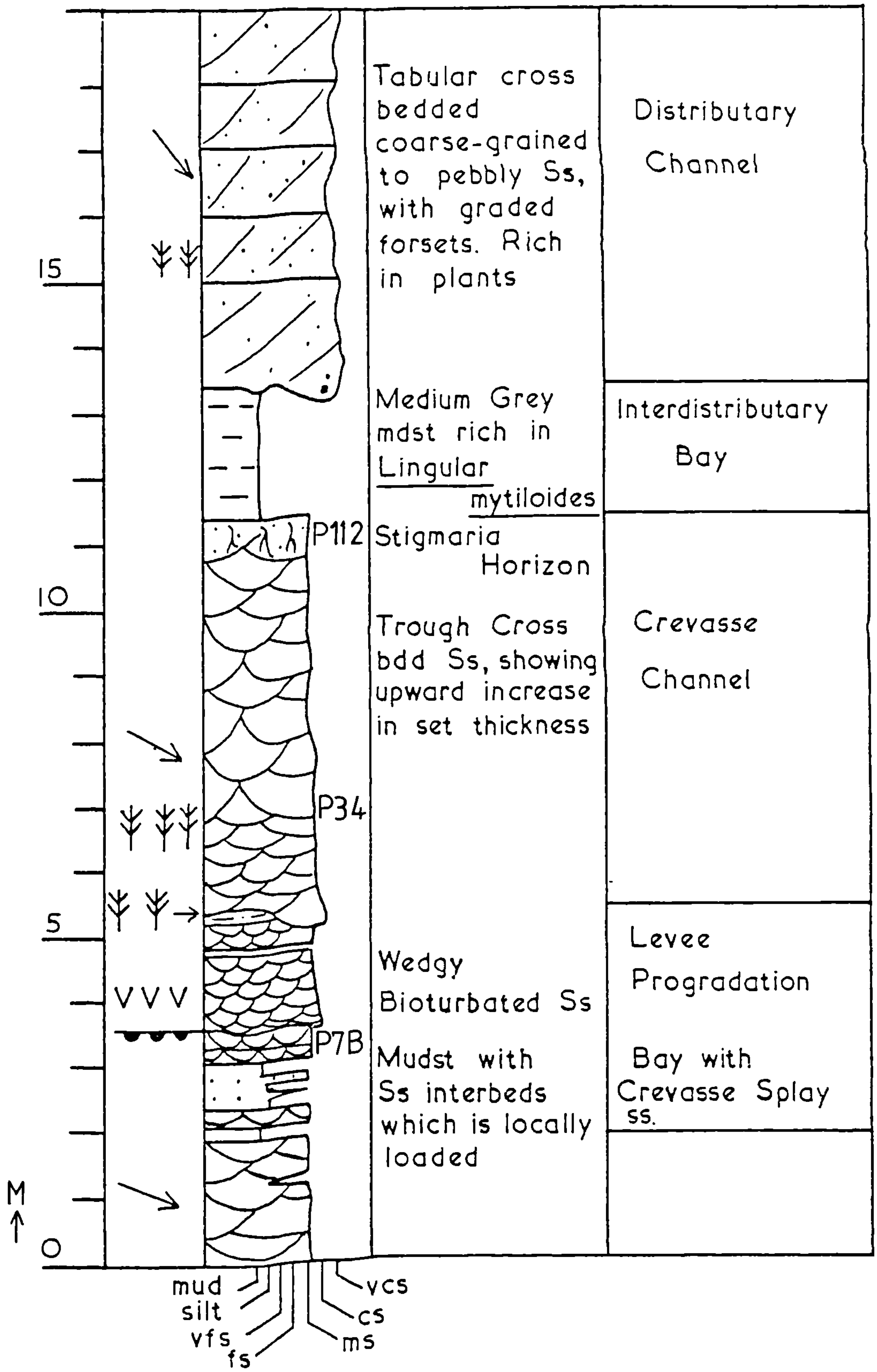

20
15
10
5
0
P84
P14
P13
Alternating tabular trough cross laminated Ss & mudstone. Pelecypodichnus destroy laminations
Inter-Distributary Bay with Minor Mouth Bar Sands
Upper Delta-Slope Sands (Proximal Mouth Bar)
mud
silt
vfs
fs
vcs
cs
ms

Fig. 82.

Detailed Vertical Section of the Pule Hill Grit in Woodhouse Quarry (SE 062397), Keighley.



Tabular cross bedded coarse-grained to pebbly Ss, with graded forsets. Rich in plants
Distributary Channel
Medium Grey mdst rich in Lingular mytiloides
Interdistributary Bay
P112
Stigmaria Horizon
Trough Cross bdd Ss, showing upward increase in set thickness
Crevasse Channel
P34
Wedgy Bioturbated Ss
Levee Progradation
P7B
Mudst with Ss interbeds which is locally loaded
Bay with Crevasse Splay ss.
15
10
5
0
M
mud
silt
vfs
fs
vcs
cs
ms

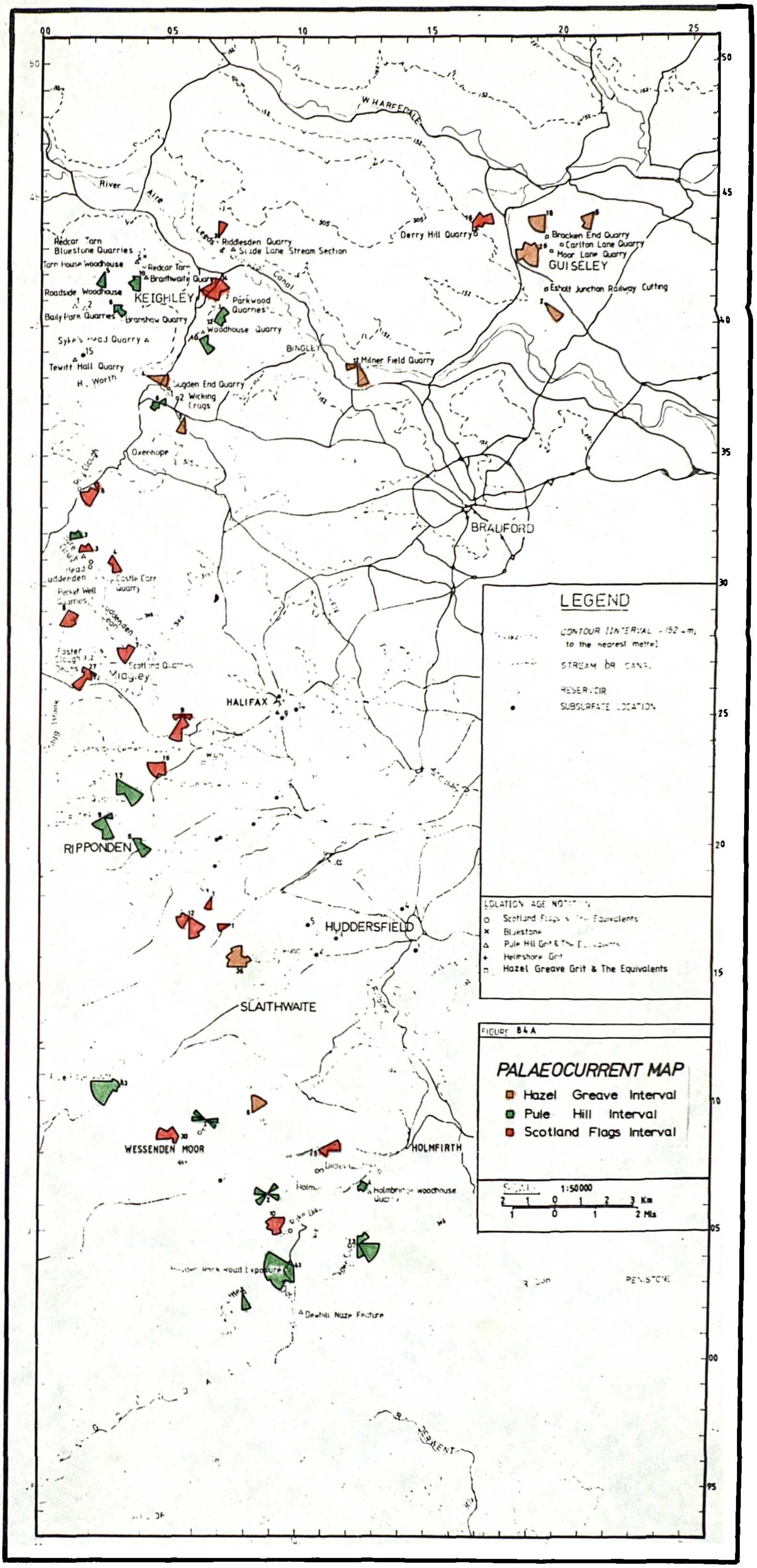
Fig. 83.

Model of Minor Mouth Bar Crevasse Channel Couplet

(See Page 215 of Volume 1).

FIG. 84A.

Palaeocurrent map of the whole of the eastern areas.



LEGEND
CONTOUR (INTERVAL - 152 m, to the nearest metre)
STREAM OR CANAL
RESERVOIR
SUBSURFACE LOCATION
LOCATION AGE NOTATION
Scotland Flags & The Equivalents
Bluestone
Pule Hill Grit & The Equivalents
Helmshore Grit
Hazel Greave Grit & The Equivalents
FIGURE 84 A
PALAEOCURRENT MAP
Hazel Greave Interval
Pule Hill Interval
Scotland Flags Interval
SCALE 1:50000
Km
Mls
WHARFEDALE
River Aire
Leeds Canal
KEIGHLEY
GUISELEY
BINGLEY
BRADFORD
HALIFAX
HUDDERSFIELD
SLAITHWAITE
RIPPONDEN
WESSENDEN MOOR
HOLMFIRTH
PENISTONE
Oxenhope
R. Worth
Redcar Tarn Bluestone Quarries
Tarn House Woodhouse
Redcar Tarn
Braithwaite Quarry
Roadside Woodhouse
Baily Park Quarries
Bramshaw Quarry
Syke's Head Quarry
Tewitt Hall Quarry
Riddlesden Quarry
Slide Lane Stream Section
Parkwood Quarries
Woodhouse Quarry
Sugden End Quarry
Wicking Crags
Milner Field Quarry
Derry Hill Quarry
Bracken End Quarry
Carlton Lane Quarry
Moor Lane Quarry
Esholt Junction Railway Cutting
Castle Carr Quarry
Scotland Quarries
Holmbridge Woodhouse Quarry
Dewhill Naze Feature
DERWENT

FIG.84B.

Palaeocurrent map of the whole of the western areas.

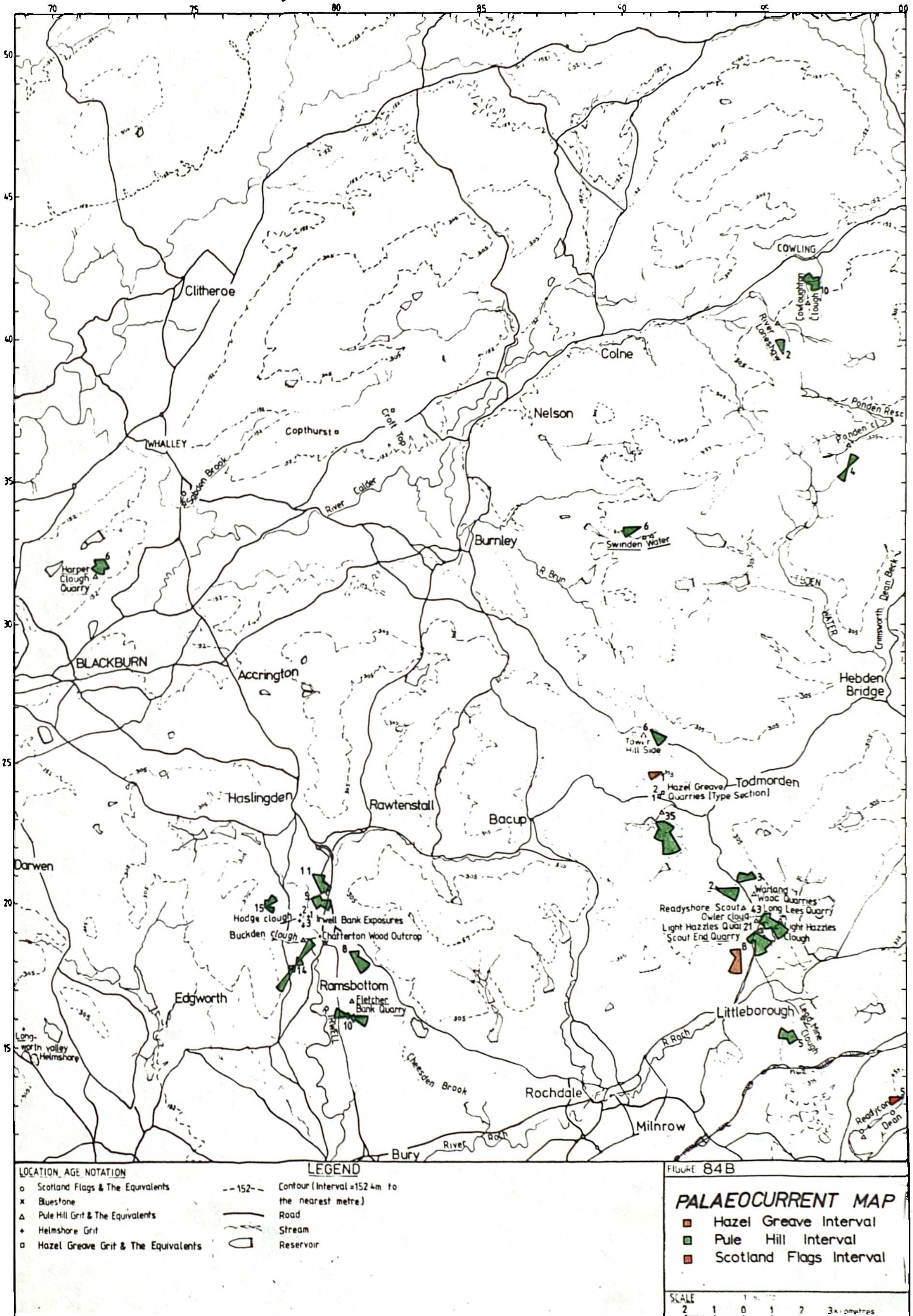
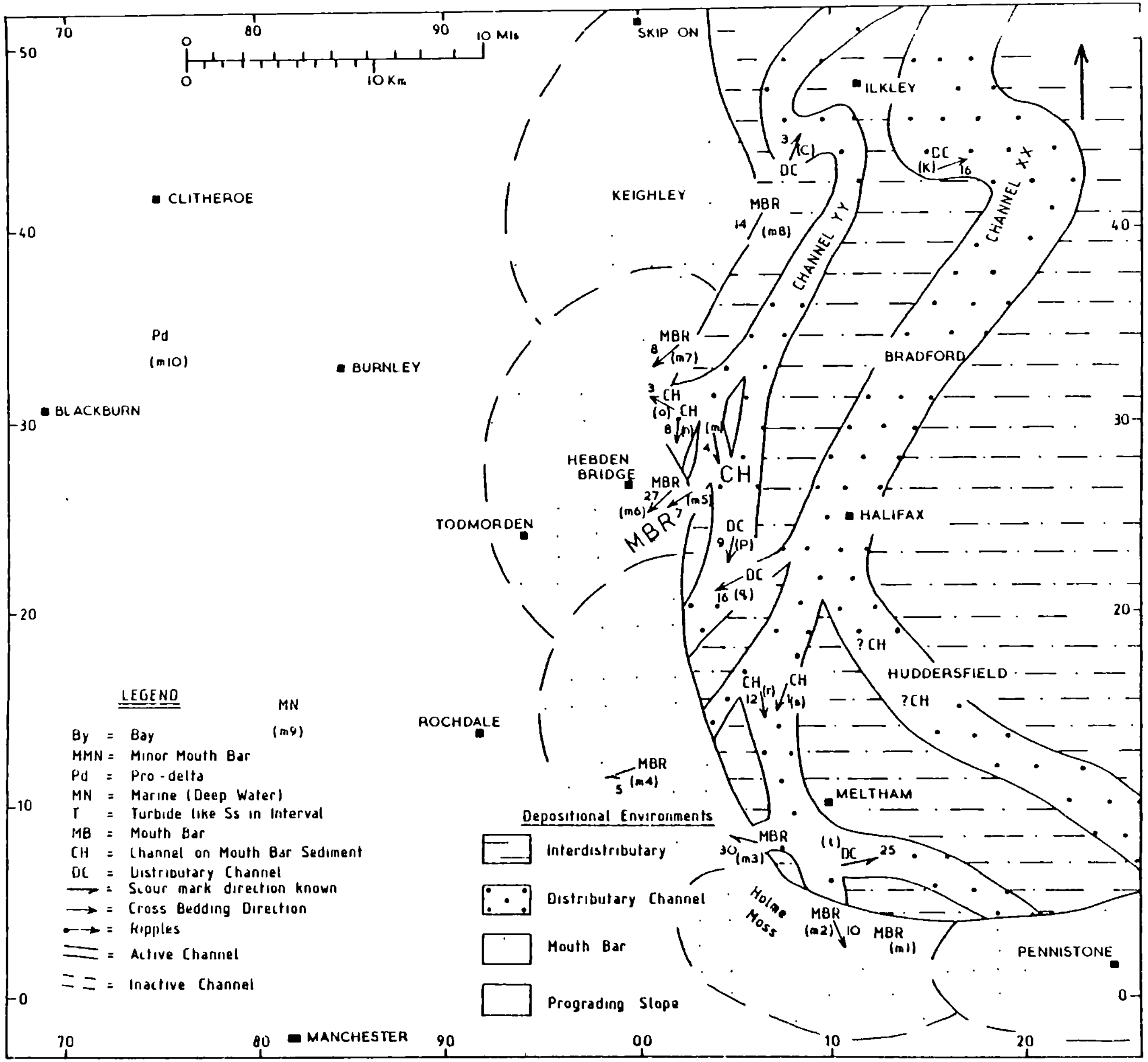


FIGURE 84B
PALAEOCURRENT MAP
Hazel Greave Interval
Pule Hill Interval
Scotland Flags Interval
LOCATION AGE NOTATION
o Scotland Flags & The Equivalents
x Bluestone
△ Pule Hill Grit & The Equivalents
+ Helmshore Grit
▫ Hazel Greave Grit & The Equivalents
LEGEND
Contour (Interval = 152.4m to the nearest metre)
Road
Stream
Reservoir
SCALE
Kilometres
Miles
Clitheroe
WHALLEY
Copthurst
Croft Top
River Calder
Sabden Brook
Colne
Nelson
COWLING
Cowloughton Clough
River Laneshaw
Ponden Resr
Ponden Cl
Burnley
Swinden Water
R. Brun
Crimsworth Dean Beck
Hebden Bridge
Harper Clough Quarry
BLACKBURN
Accrington
Haslingden
Rawtenstall
Bacup
Todmorden
Tower Hill Side
Hazel Greave Quarries (Type Section)
Darwen
Hodge clough
Irwell Bank Exposures
Buckden Clough
Chatterton Wood Outcrop
Readyshore Scout
Owler clough
Warland Wood Quarries
Long Lees Quarry
Light Hazzles Quarry
Light Hazzles Clough
Scout End Quarry
Ramsbottom
Fletcher Bank Quarry
Edgworth
Littleborough
Longmere Clough
Longworth valley
Helmshore
Cheesden Brook
R. Roch
Rochdale
Milnrow
Bury
River Roch
Readycon Dean

Fig. 85.

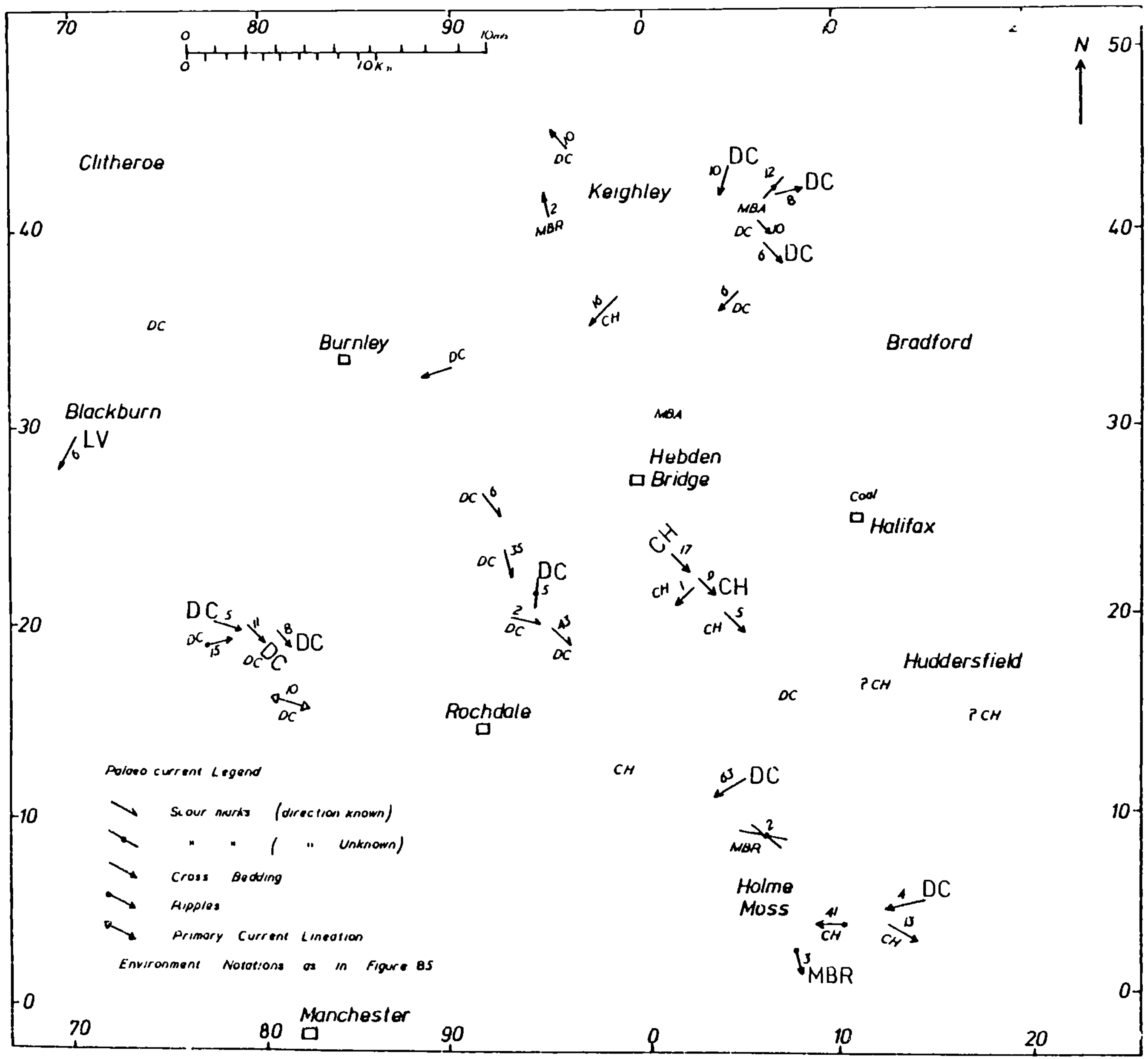
Envisaged Palaeogeographic Map of Central Pennine Basin at the end of the Scotland Flags Interval (immediately pre-*R. bilingue* typical).



SKIP ON
ILKLEY
KEIGHLEY
CLITHEROE
BURNLEY
BLACKBURN
BRADFORD
HALIFAX
HEBDEN BRIDGE
TODMORDEN
HUDDERSFIELD
ROCHDALE
MELTHAM
PENNISTONE
MANCHESTER
Holme Moss
CHANNEL XX
CHANNEL YY
10 Mls
10 Km
Pd
(m10)
MN
(m9)
LEGEND
By = Bay
MMN = Minor Mouth Bar
Pd = Pro-delta
MN = Marine (Deep Water)
T = Turbide like Ss in Interval
MB = Mouth Bar
CH = Channel on Mouth Bar Sediment
DC = Distributary Channel
= Scour mark direction known
= Cross Bedding Direction
= Ripples
= Active Channel
= Inactive Channel
Depositional Environments
Interdistributary
Distributary Channel
Mouth Bar
Prograding Slope

Fig. 86.

Envisaged Palaeogeographic map of the Central Pennine Basin at the End of Pule Hill Interval (immediately pre- *R. bilingue* late).



Clitheroe
Blackburn
Burnley
Keighley
Bradford
Hebden Bridge
Halifax
Huddersfield
Rochdale
Holme Moss
Manchester
Coal
N
10 Km
10 K
Palaeo current Legend
Scour marks (direction known)
" " (" Unknown)
Cross Bedding
Ripples
Primary Current Lineation
Environment Notations as in Figure 85

Fig. 87.

Envisaged Palaeogeographic map of the Central Pennine Basin at the end of Hazel Greave Interval.

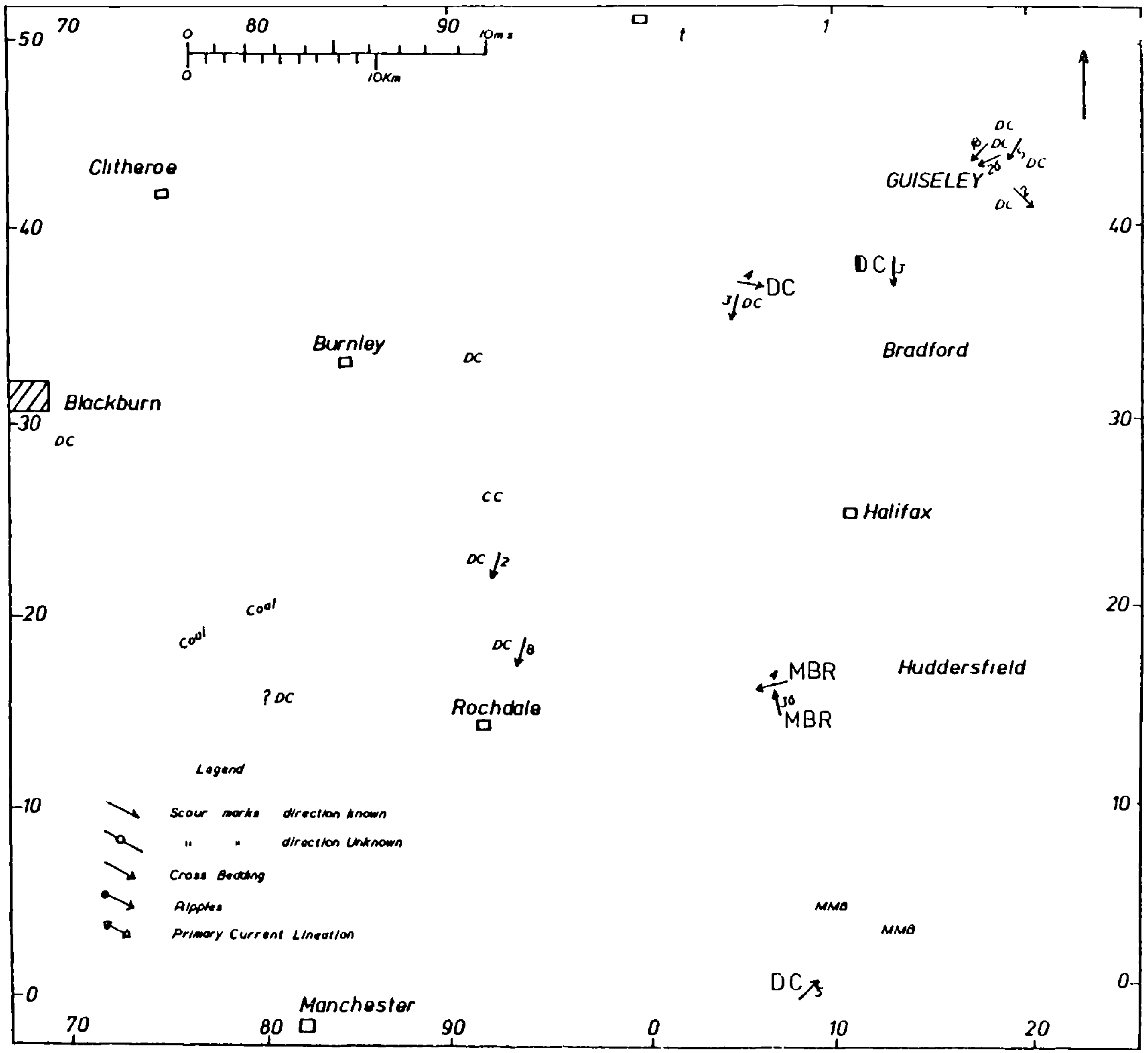
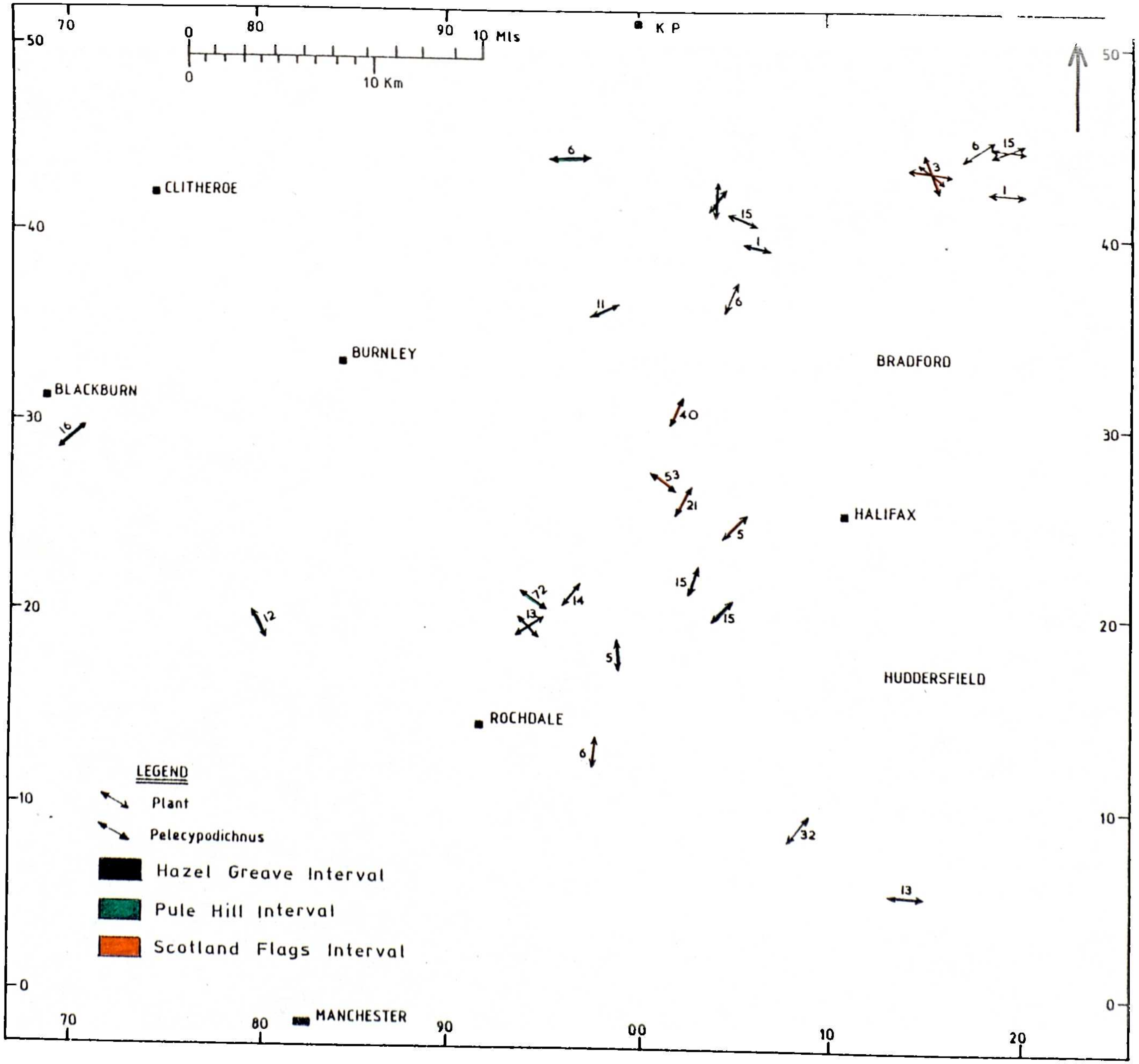

10Km
10ms
Clitheroe
Blackburn
Burnley
GUISELEY
Bradford
Halifax
Huddersfield
Rochdale
Manchester
MBR
MBR
MMB
MMB
DC
CC
Coal
Coal
? DC
Legend
Scour marks direction known
" " direction Unknown
Cross Bedding
Ripples
Primary Current Lineation

Fig. 88.

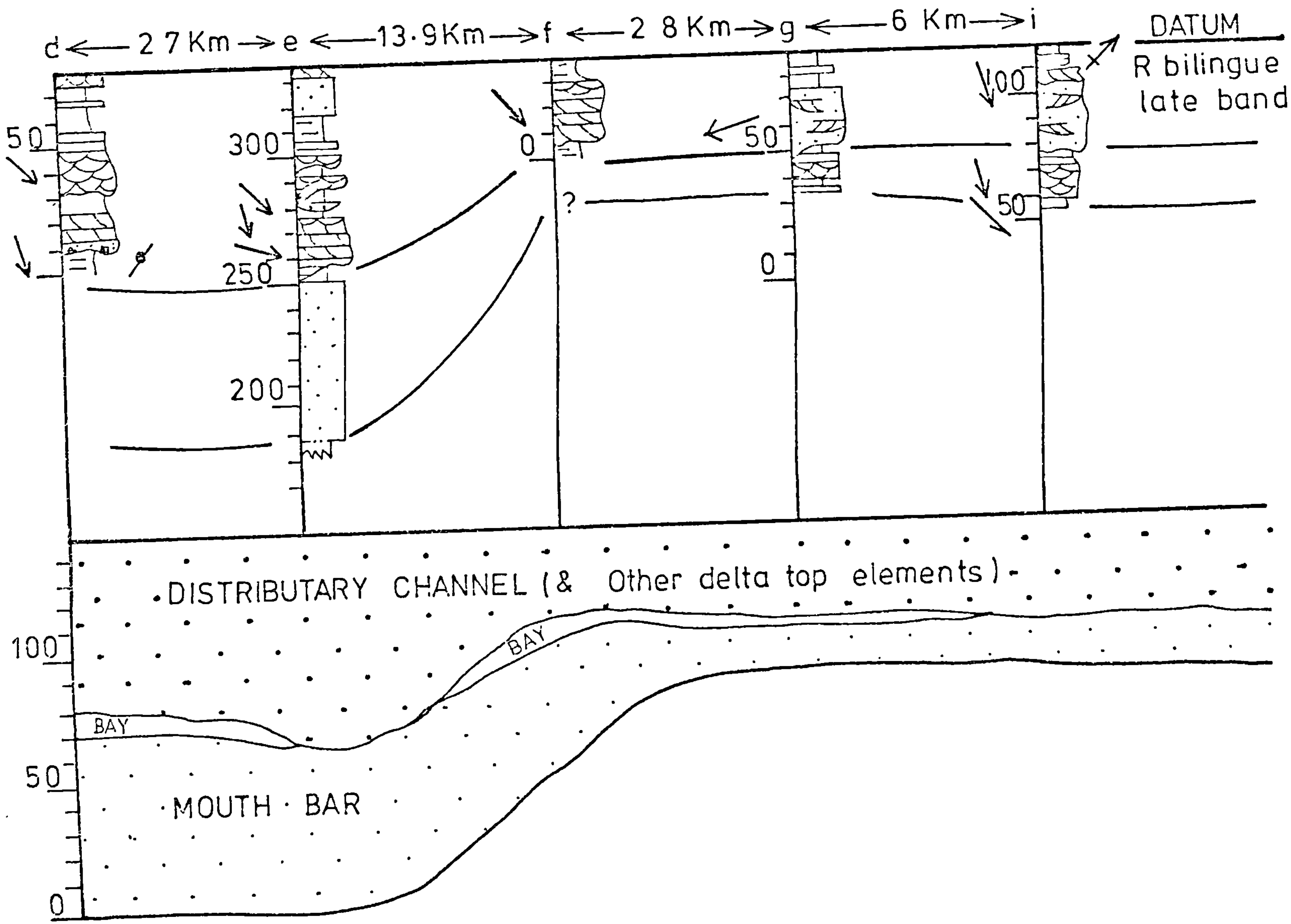
Map of the whole area showing the orientation of Plants and *Pelecypodichnus* in Marsdenian sediments.



K P
10 Mls
10 Km
CLITHEROE
BURNLEY
BLACKBURN
BRADFORD
HALIFAX
HUDDERSFIELD
ROCHDALE
MANCHESTER
LEGEND
Plant
Pelecypodichnus
Hazel Greave Interval
Pule Hill Interval
Scotland Flags Interval

Fig. 89.

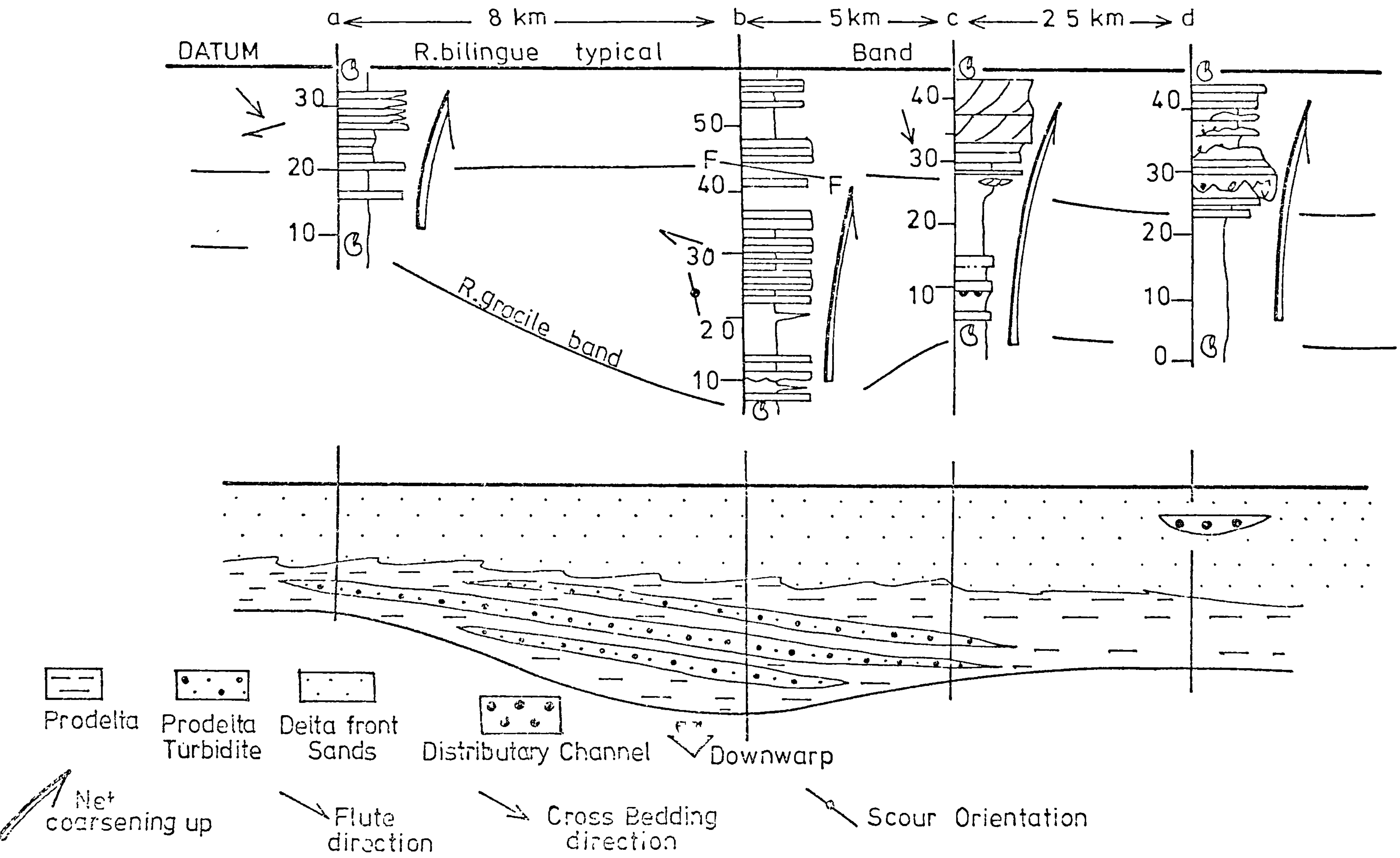
Model of Pule Hill Delta in area 4. Note the sheet-like geometry of the Mouth Bar and the Distributary Channel Sandstone units and the truncation of the upper parts of the Mouth-Bar Sands by the Distributary Channels. Vertical Scale in metres.



d ← 2 7 Km → e ← 13·9 Km → f ← 2 8 Km → g ← 6 Km → i
DATUM
R bilingue
late band
50
300
250
200
0
50
0
100
50
?
DISTRIBUTARY CHANNEL (& Other delta top elements)
BAY
BAY
MOUTH · BAR
100
50
0

Fig. 90.

Model of Scotland Flags Delta in area 1. Note the sheet-like geometry of the Mouth Bar Sands and the presence of Prodelta Turbidites in the Scotland Flags Mudstone (Prodelta). Vertical Scale in metres.



a
8 km
b
5km
c
2 5 km
d
DATUM
R.bilingue typical Band
R.gracile band
30
20
10
50
40
F
F
0
Prodelta
Prodelta Turbidite
Delta front Sands
Distributary Channel
Downwarp
Net coarsening up
Flute direction
Cross Bedding direction
Scour Orientation

Fig. 91.

Principal depositional Environments, high constructive Lobate Delta Lafourche Delta (From Fisher *et al.* 1969).

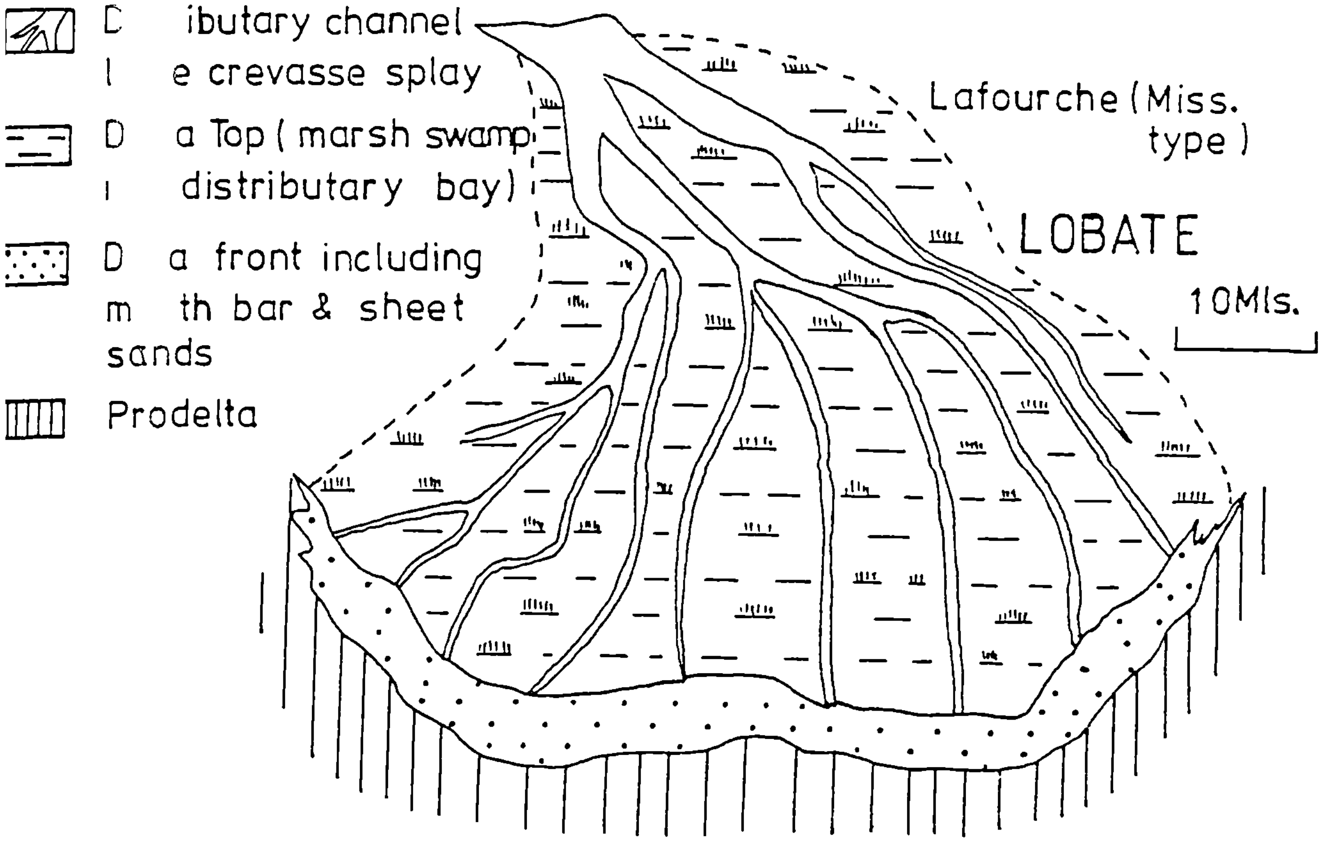

D ibutary channel
l e crevasse splay
D a Top (marsh swamp
i distributary bay)
D a front including
m th bar & sheet
sands
Prodelta
Lafourche (Miss.
type)
LOBATE
10Mls.

Fig. 92.

Toponomic classification of bioturbation structures (from A. Seilacher, 1953).

Fig. 93.

Toponomic classification of bioturbation structures (From A. Martinsson, 1970).

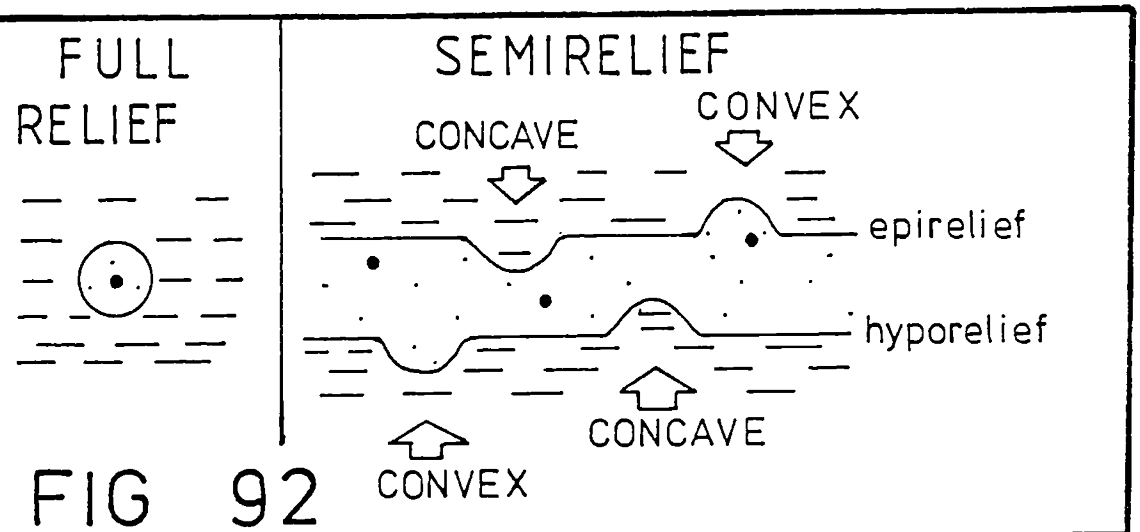

FULL
RELIEF
SEMIRELIEF
CONCAVE
CONVEX
epirelief
hyporelief
CONVEX
CONCAVE

FIG 92

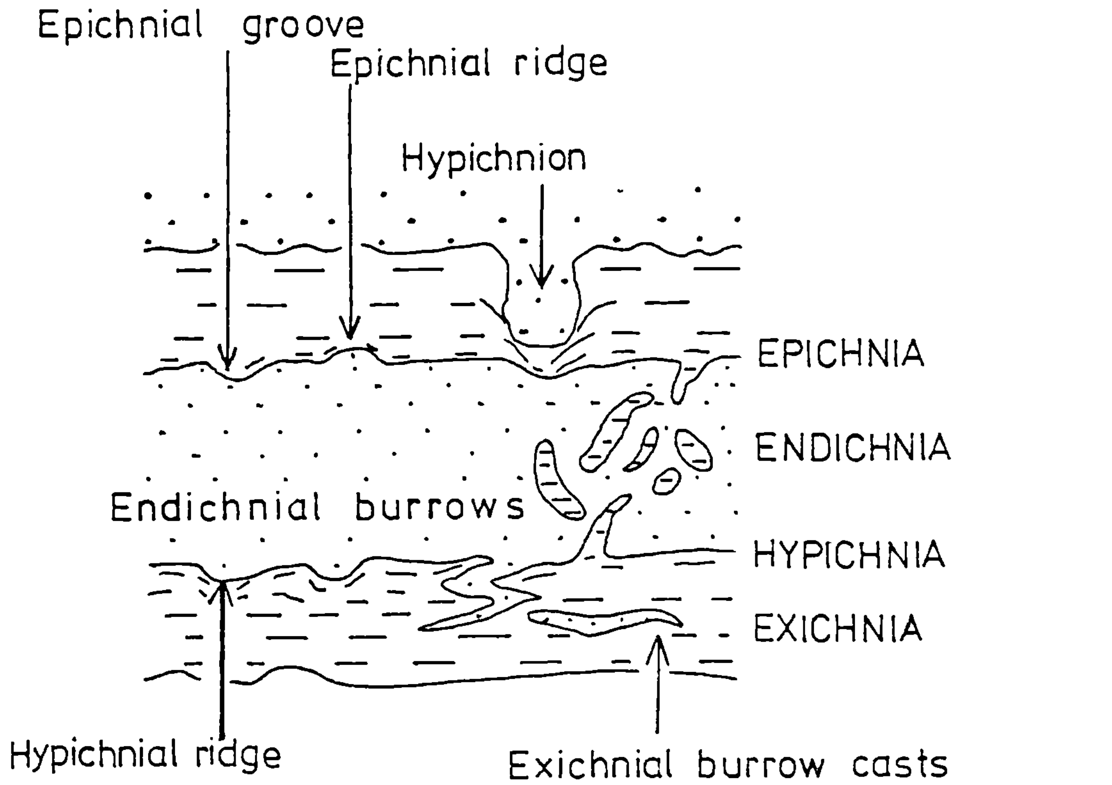
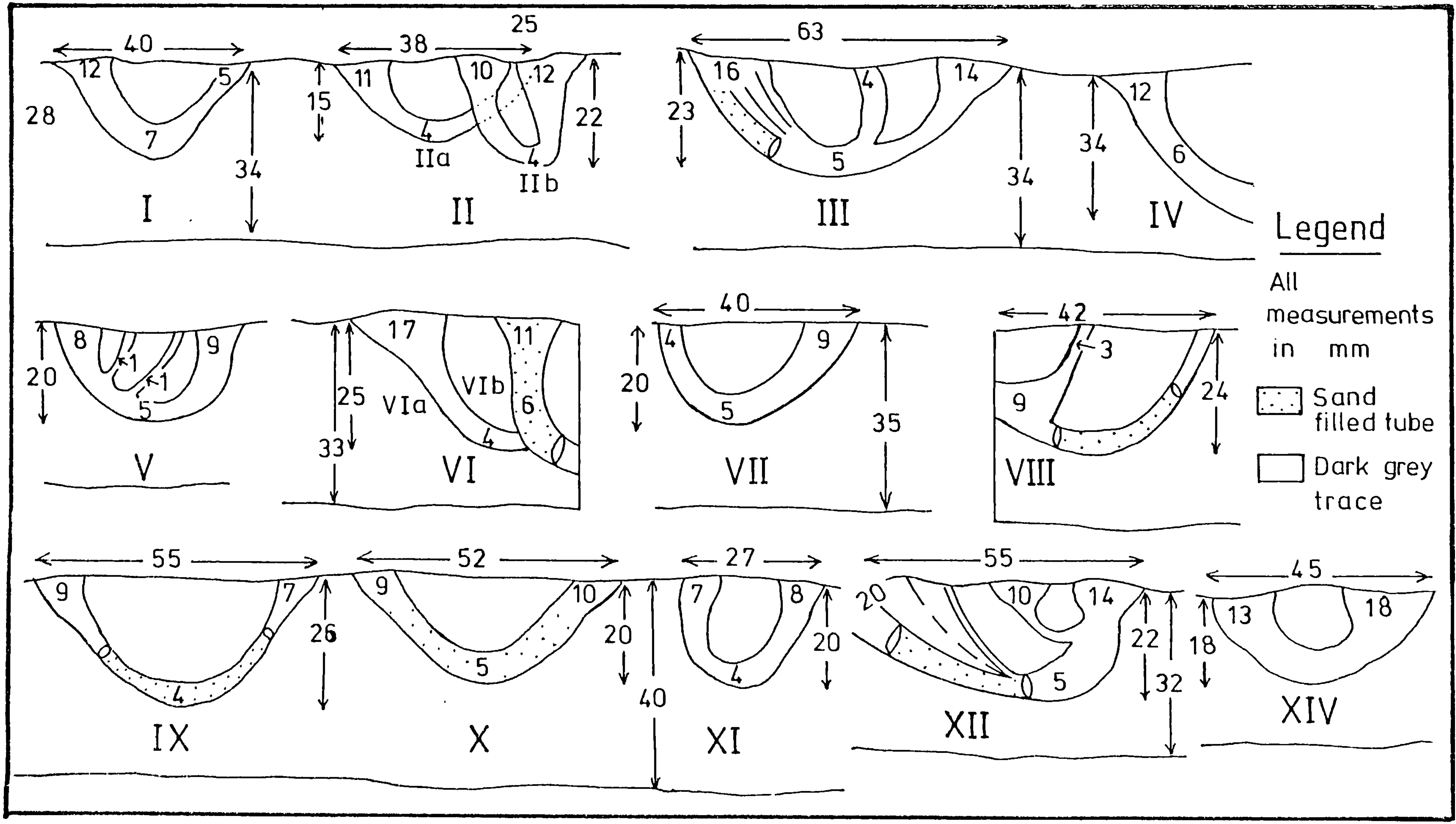

Epichnial groove
Epichnial ridge
Hypichnion
EPICHNIA
ENDICHNIA
Endichnial burrows
HYPICHNIA
EXICHNIA
Hypichnial ridge
Exichnial burrow casts

FIG 93

Fig. 94.

Traced sketch of samples showing Arenicolites burrow in Lithofacies 9, Parallel Laminated Sandstone of Crevasse Splay origin in Pule Hill Grit at Fletcher Bank Quarry (SD 801167, 50-51m level, Fig. 59. Northern Vertical Section).



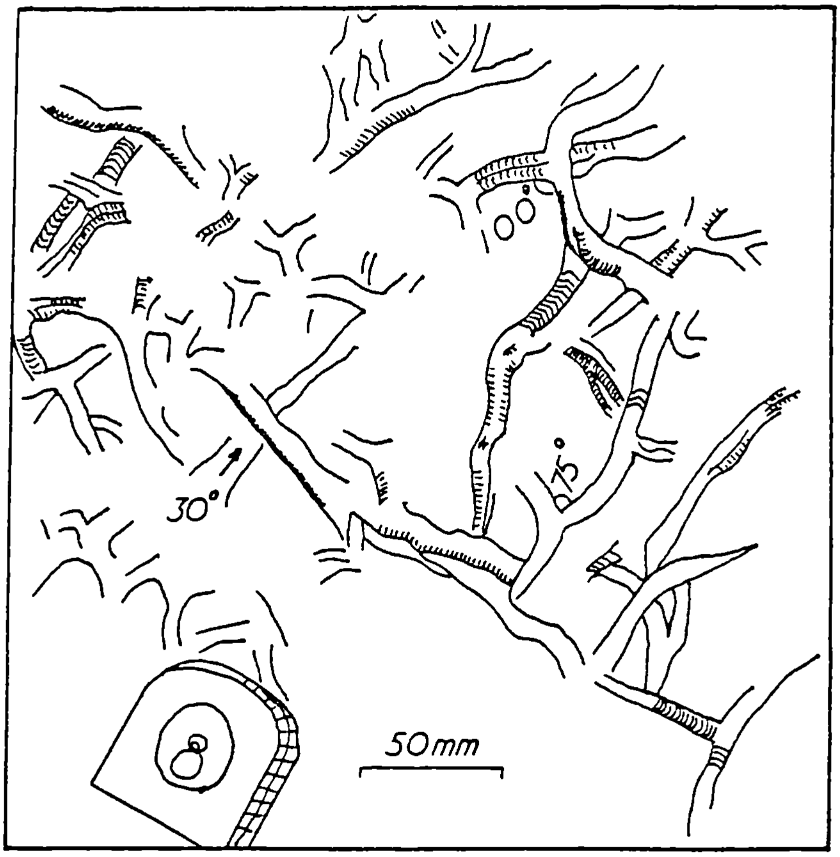
Legend
All measurements in mm
Sand filled tube
Dark grey trace
I
II
IIa
IIb
III
IV
V
VI
VIa
VIb
VII
VIII
IX
X
XI
XII
XIV

Fig. 95.

Traced sketch of photograph (Plate 118) showing cross-cutting tubes of *Arthrophycus*. (Note the branching angles). Pule Hill Grit Sequence, Fletcher Bank Quarry 26-28m level, Fig. 59. Northern Vertical Section.

Fig. 96.

Traced sketch of photographs (Plate 119) showing assemblage of *Gyrophyllites* (1), *?Phycodes palmatum* (4, 5), *Kouphichnium* (3), *Cochlichnus* (6) and Pelecypodichnus (2) in Park Wood Quarry 3. Pule Hill Grit (SE 067406, 64-70m level, Fig. 15 'd' sequence).

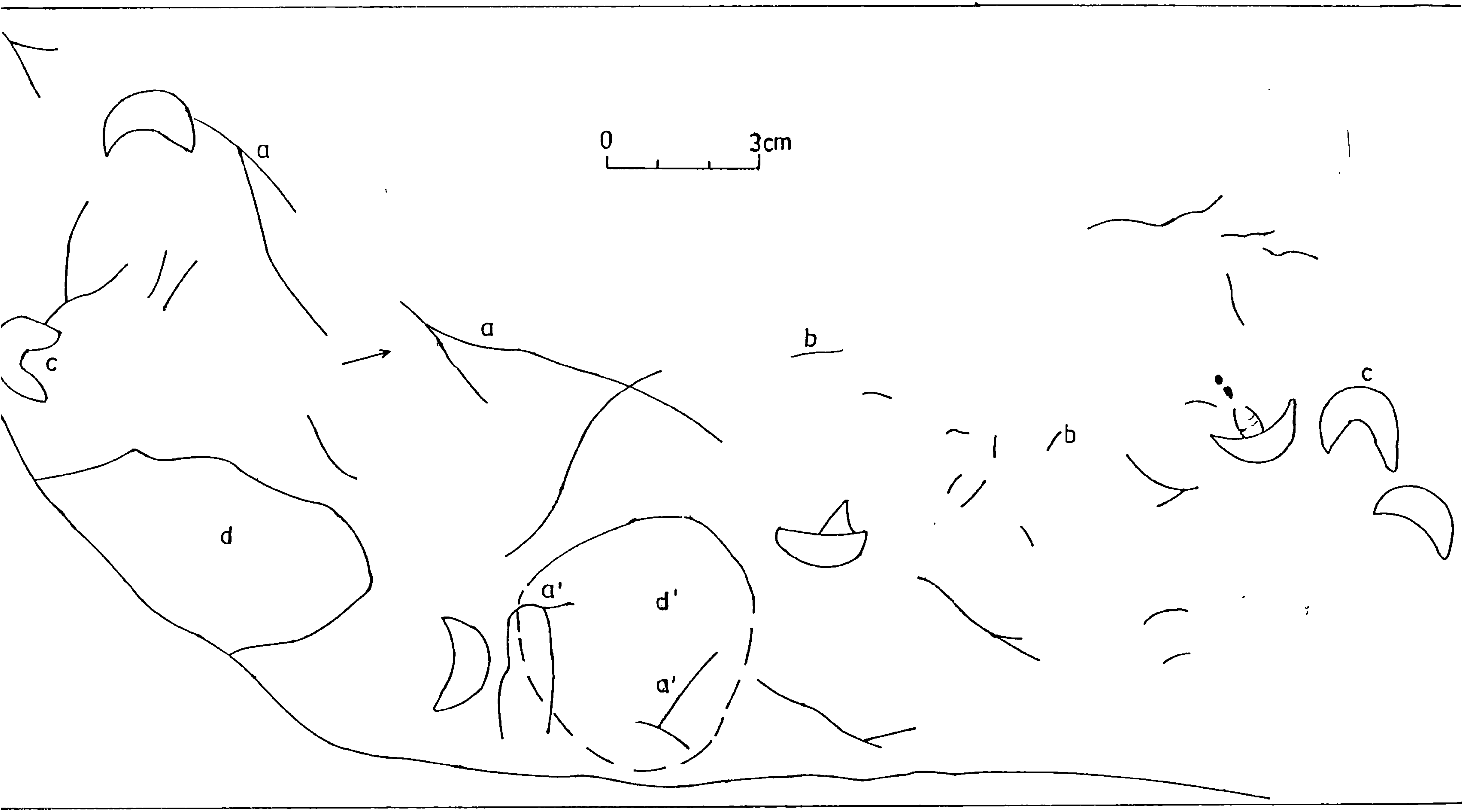


100°
75°
30°
50mm

6
2
6
6
30cm
4
5
10p
2
6
1
1
3
3
1

Fig. 97A.

Traced sketch of photograph showing assemblage of Palaeophycus (a), Planolites (b), Kouphichnium (c) in Lithofacies 10, Trough Cross bedded sandstone (Mouth Bar) in Hazel Greave Grit at Scout End (SD 944190, 6.3m level of Fig. 80). Note the cross-cutting relationship between the trace fossil and the load structure 'd' and also between the fossil and ichnogenus Kouphichnium (left of figure).



0
3cm
a
a
b
b
c
c
d
d'
a'
a'

Fig. 97B.

Traced sketch of photograph showing assemblage of *Planolites* (a), *Kouphichnium* (c), *Palaeophycus* (b) in Lithofacies 10, Trough Cross Bedded Sandstone (Mouth Bar area) in Pule Hill Grit at Park Wood Quarry 2 (SE 070409).

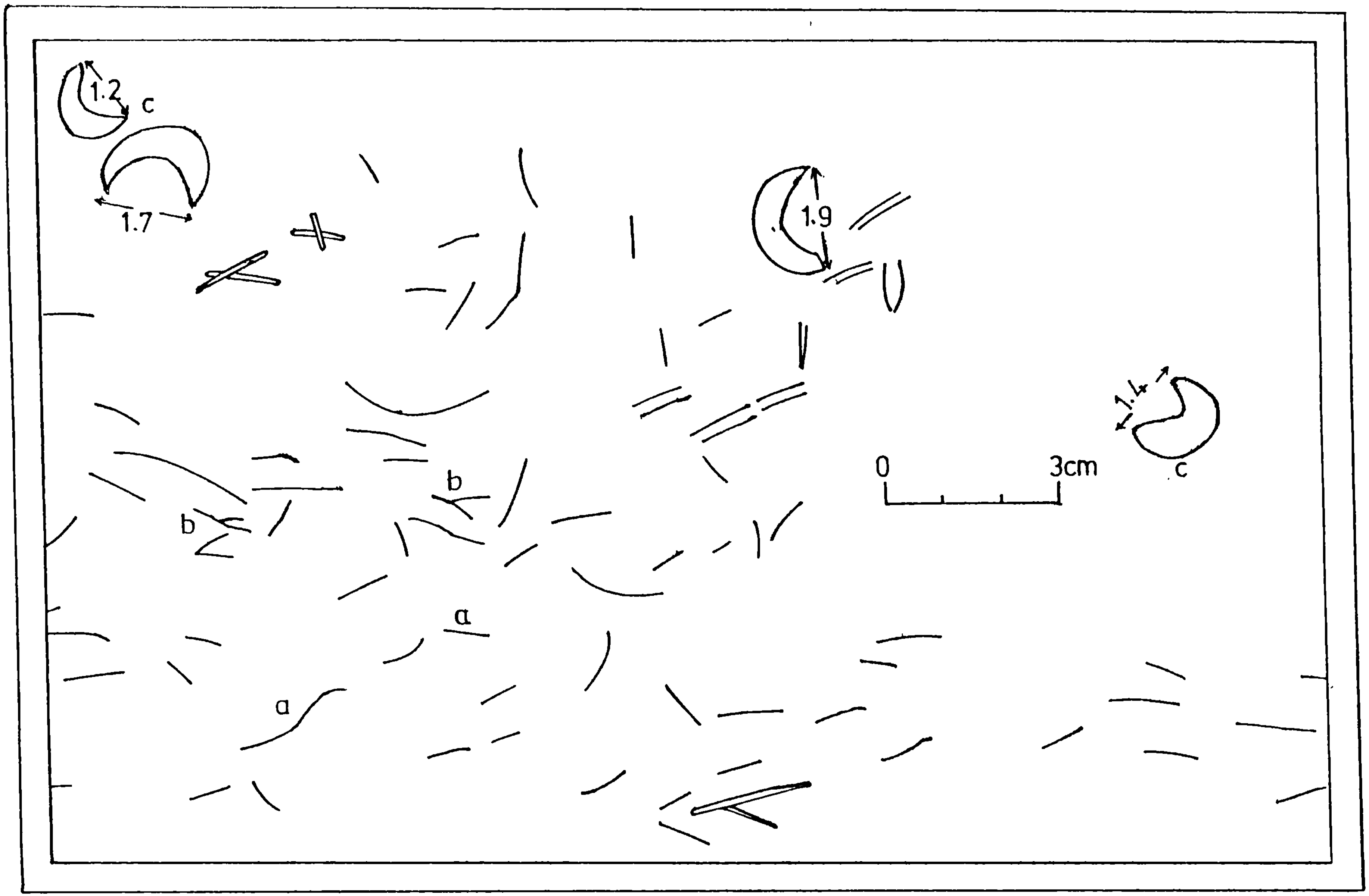
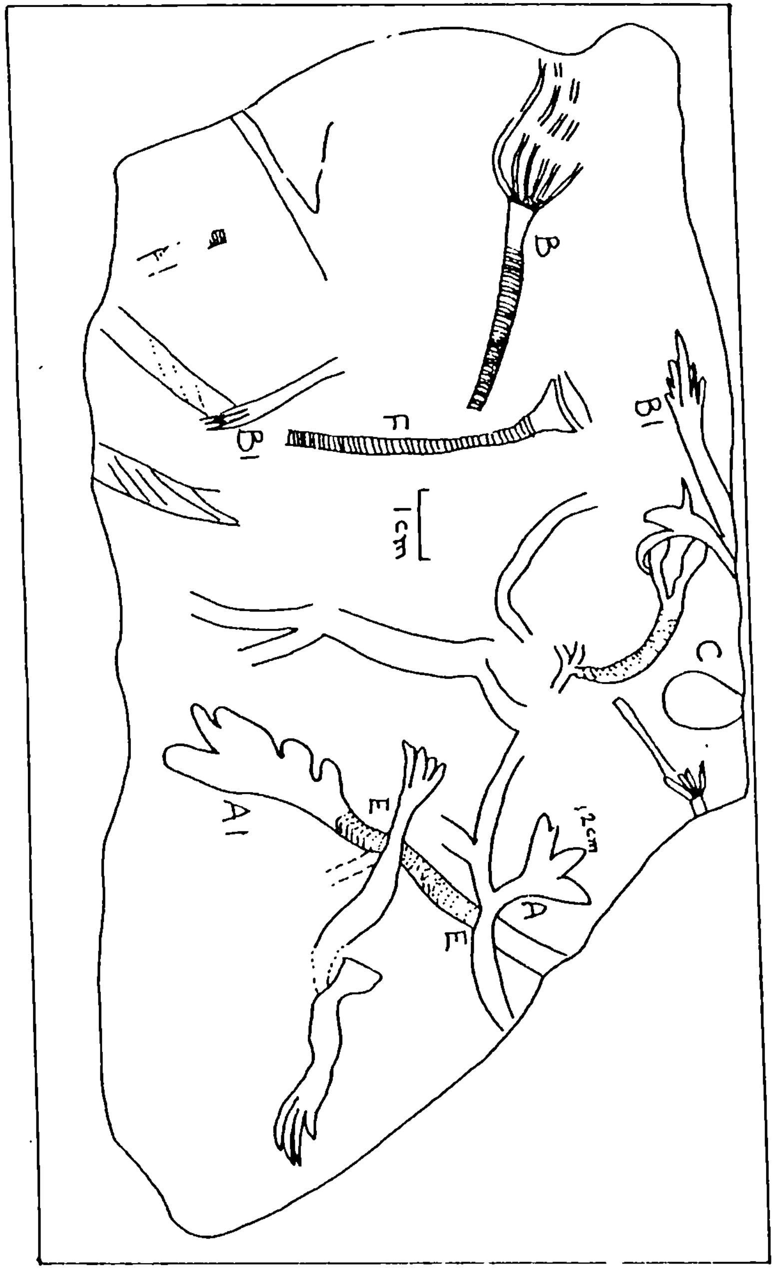

1.2
c
1.7
1.9
b
b
a
a
0
3cm
1.4
c

Fig. 98.

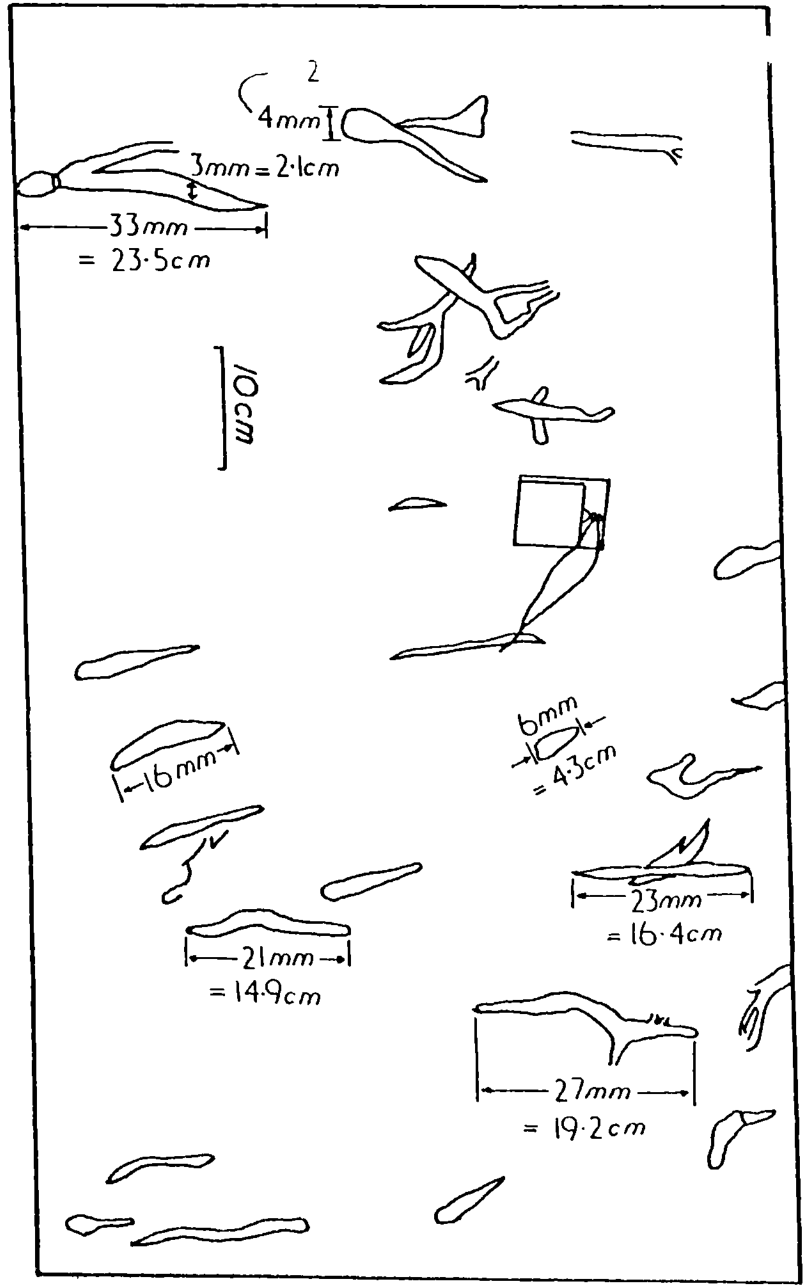
Traced sketch of photograph (Plate 122) showing Palaeophycus at Fletcher Bank Quarry. Note the common branching of tubes. (SD 806167, Pule Hill Grit. Lithofacies 10, Trough Cross Bedded Sandstone of the Distributary Channel 2, 15m level Southern Vertical Section Fig. 59).

Fig. 99.

Traced sketch of photograph (Plate 134) showing feeding structures of Phycodes curvipalmatum in the sole of a lithofacies 13, Scour based sand body (Distributary Channel) in the downthrown Hazel Greave Grit at Wicking Crag Quarry (SE 052372). Note cross-cutting of tubes, petalloid manner of tube branching (A, A1), simple finger-like branches (B, B1) radiation of tubes from a common point (E), annulated tubes (F).



B
B1
B1
F
1cm
C
A1
E
E
A
1.2cm



2
4mm
3mm = 2·1cm
33mm
= 23·5cm
10cm
6mm
= 4·3cm
16mm
23mm
= 16·4cm
21mm
= 14·9cm
27mm
= 19·2cm

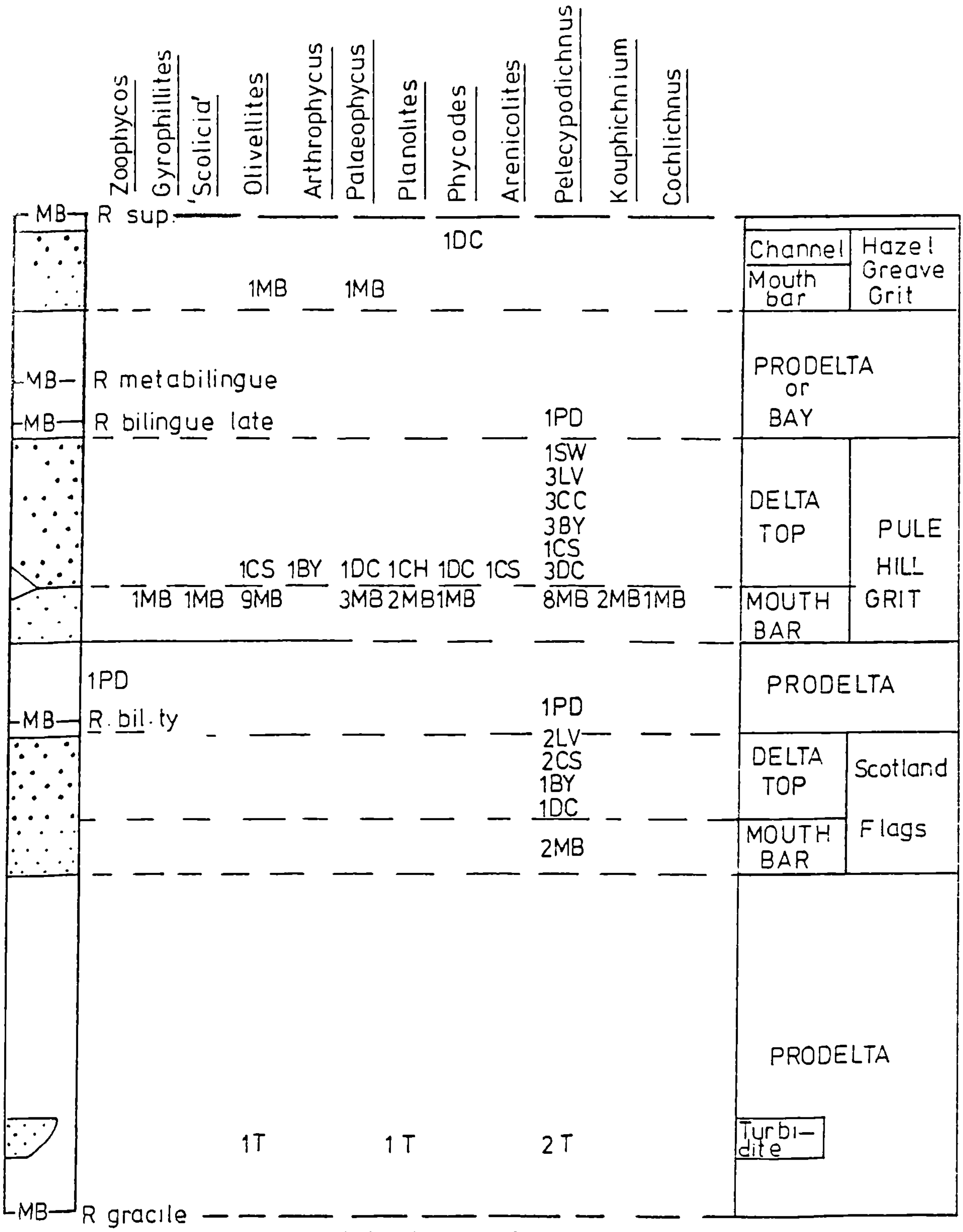
Fig. 100

Traced sketch of photograph (Plate 135) showing complex feeding structures of Phycodes curvipalmatum and a structure resembling cf. Nereites (arrowed) in Wicking Crag Quarry. (Fig. 100 is from the same quarry and level as Fig 99 but shows the more complex cross-cutting of tubes.


0
3cm

Fig. 101.

Distribution of Trace Fossils of Marsdenian Sediments in Central Pennine Basin.



See legend in fig 16 for environmental notations

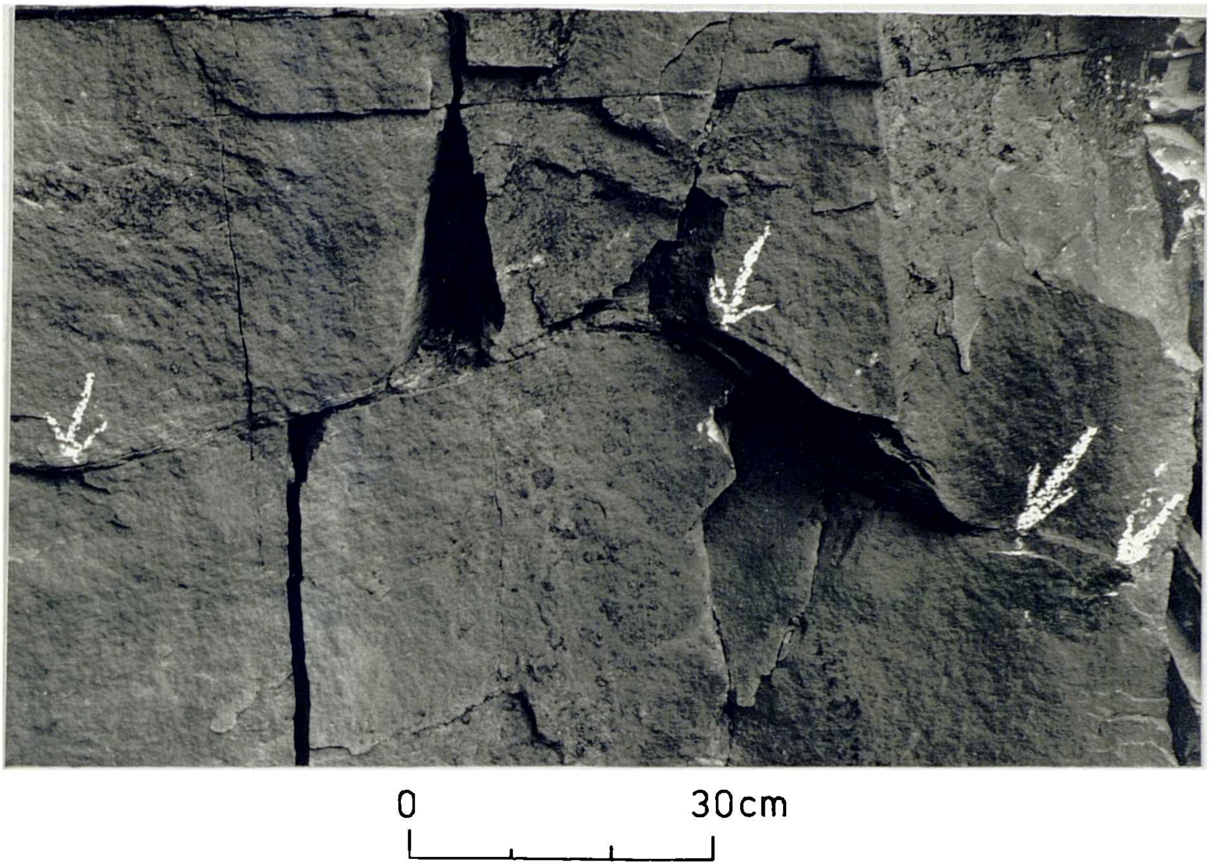
SECTION II. PLATES

Plate 1

Lower Parts of Scotland Flags (Mouth Bar area; level 0-60cm. Vertical Section 1, Fig 55) in Scotland Flags Quarry, Midgley (SE 033268) showing well bedded sandstone. Arrows point to undulating thin mud flake unit occurring between beds. (Horizontal stratification of beds indistinct in picture).

Plate 2

Upper parts of Scotland Flags (Mouth Bar area; Bay and Crevasse Channel; level 7-16m, Vertical Section 1, Fig 55) in Scotland Flags Quarry, Midgley showing sandstone and mudstone interbeds.


0
30cm


tape1m

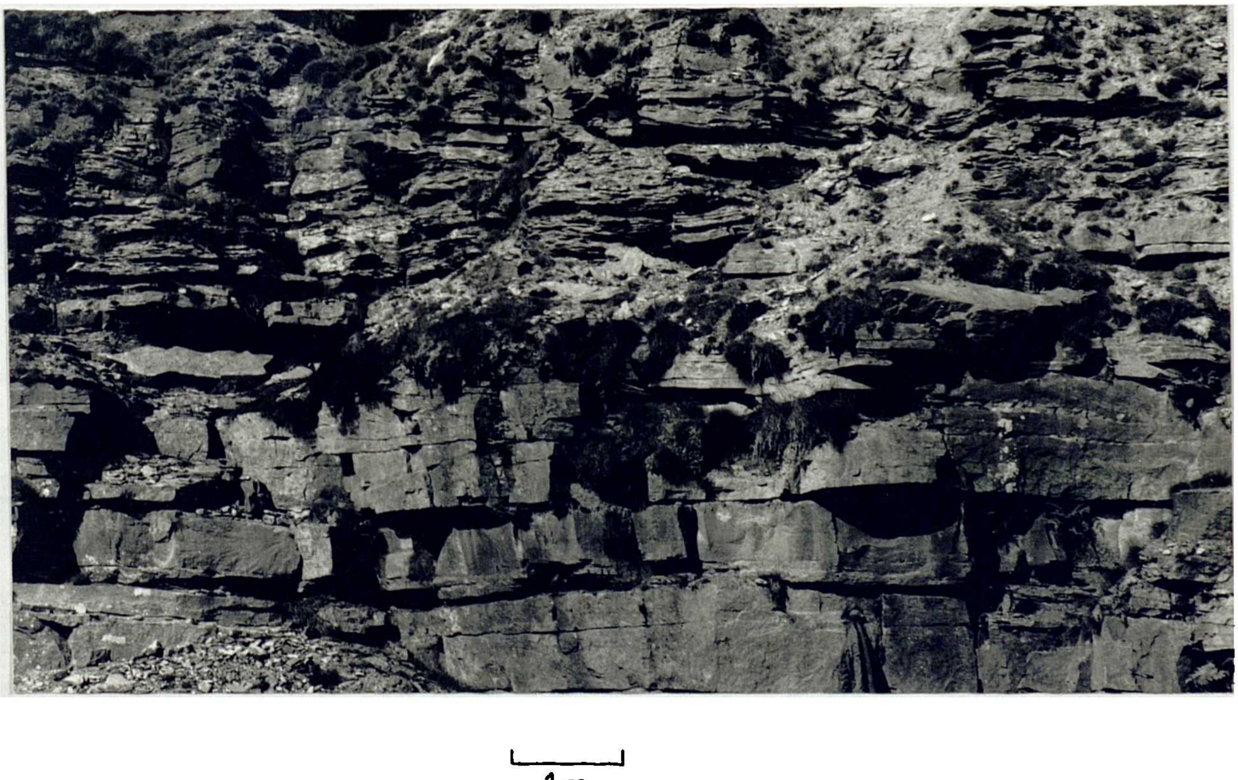
Plate 3

Lower parts of Scotland Flags (Mouth Bar; levels 3-10m, Fig 77) in Foster Clough Quarries showing thickly bedded sandstone. (Chalk marks along stratification planes).

Plate 4

Upper parts of Scotland Flags (Levee Sequence; levels 16.2-18m, Fig 77) in Foster Clough Quarries showing interbeds of sandstone and mudstone which are progressively thinner upwards.

1m



1m

Plate 5

30cm thick coal on a 63cm thick seatearth (Marsh) capping the Scotland Flags Sequence (plate 6) in Park Wood Quarry No. 1. (Lower tape on seatearth, hammer in coal; level 13-14m, No. 2 Vertical Section, Fig 19).

Plate 6

Scotland Flags Sequence (Mouth Bar) in Park Wood Quarry 1 consisting of interbeds of lithofacies 8, Trough Cross laminated sandstone (thin to thick-bedded) and lithofacies 1, Unfossiliferous Mudstone. Note the gradational bases of sandstone interbeds (Level 8.3-13m, No. 2 Vertical Section, Fig 19; Tape exposed is 1m, hammer is 33cm).

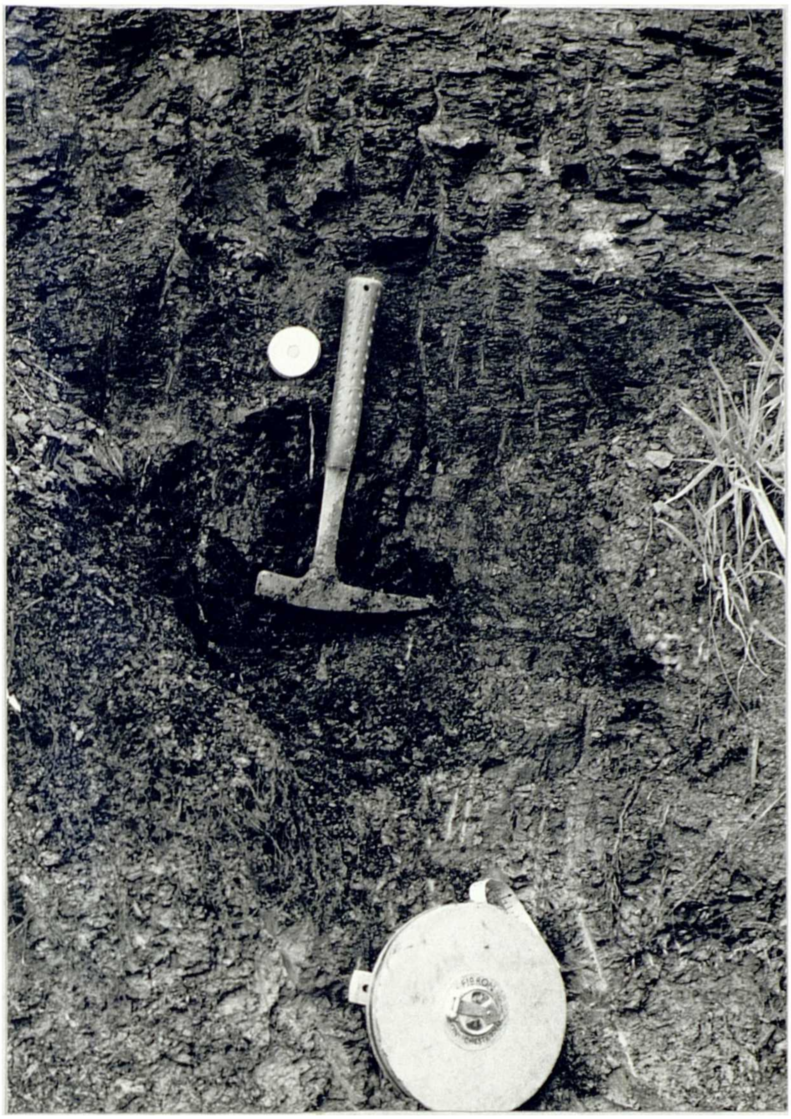


Plate 7A

Lithofacies 16, Parallel sided sandstone in the Upper parts of the Scotland Flags Sequence (levee sequence) of Foster Clough Quarry (SE 021273); level 15.3m, fig 73). Note the flute (arrowed) at the sharp erosive base.

Plate 7B

Lithofacies 16, Parallel sided sandstone, in the lower parts of Pole Hill Grit sequence (Levee progradation) of Woodhouse Quarry (SE 062397; level 3.2m, Fig 82). Note the sharp erosional base and the symmetrically rippled upper surfaces.

0 30cm

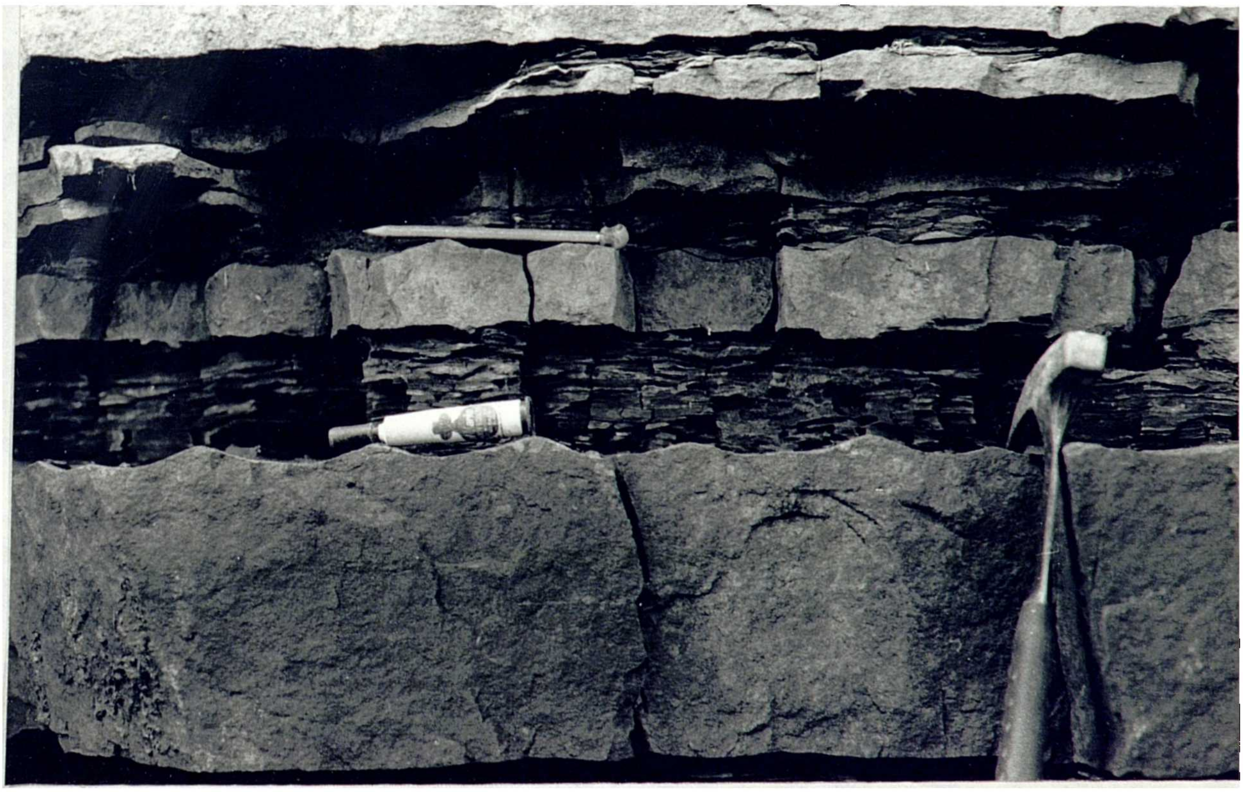


Plate 8

Thickly bedded sandstone (part of Scour Based Sand bodies, channels, of plate 73) in Pole Hill Grit type section (SE 032106). Diameter of Tape Reel (or head) is 17cm. (See Plate 73 for the position of Plate 8 in Plate 73).

Plate 9

Olivellites, crawling traces of Isopods, on the bedding plan of lithofacies 14, Horizontal Bedded Sandstone (Mouth Bar) in Bare Clough (Level 36-42m, a sequence, Fig 14, Nicon Cap is 5.5cm in diameter).


Tape Head


Nikon

Plate 10A

Symmetrical Ripples at top of lithofacies 10, Trough Cross Bedded Sandstone (Mouth Bar Area) in Pule Hill Grit of Park Wood Quarry 3 (SE 067406). (Compass is 10cm long).

Plate 10B

Symmetrical Ripples preserved as cast at the base of Lithofacies 10, Trough Cross Bedded sandstone (Mouth Bar Area) in Pule Hill Grit of Park Wood Quarry 3 (SE 067406).

0 1m

Plate 11

Siliceous ferruginous claystone nodules of lithofacies 2, Fossiliferous Mudstone (Marine Prodelta), aligned along a horizontal line (arrowed) in Hazel Greave Mudstone of Sunny Bank Cutting (SD 780206; 7m level, b sequence, Fig 16).

The extreme right nodule is

plate 100; hammer 33cm).

Plate 12

Siliceous ferruginous claystone bands of lithofacies 2, Fossiliferous Mudstone (Marine Prodelta) aligned along distinct levels (arrowed) in Hazel Greave Mudstone of Harper Clough Quarry (SD 717318; 28m level, b sequence, Fig 17). Note the contrast in colour between the bands and the surrounding mudstone sediments.

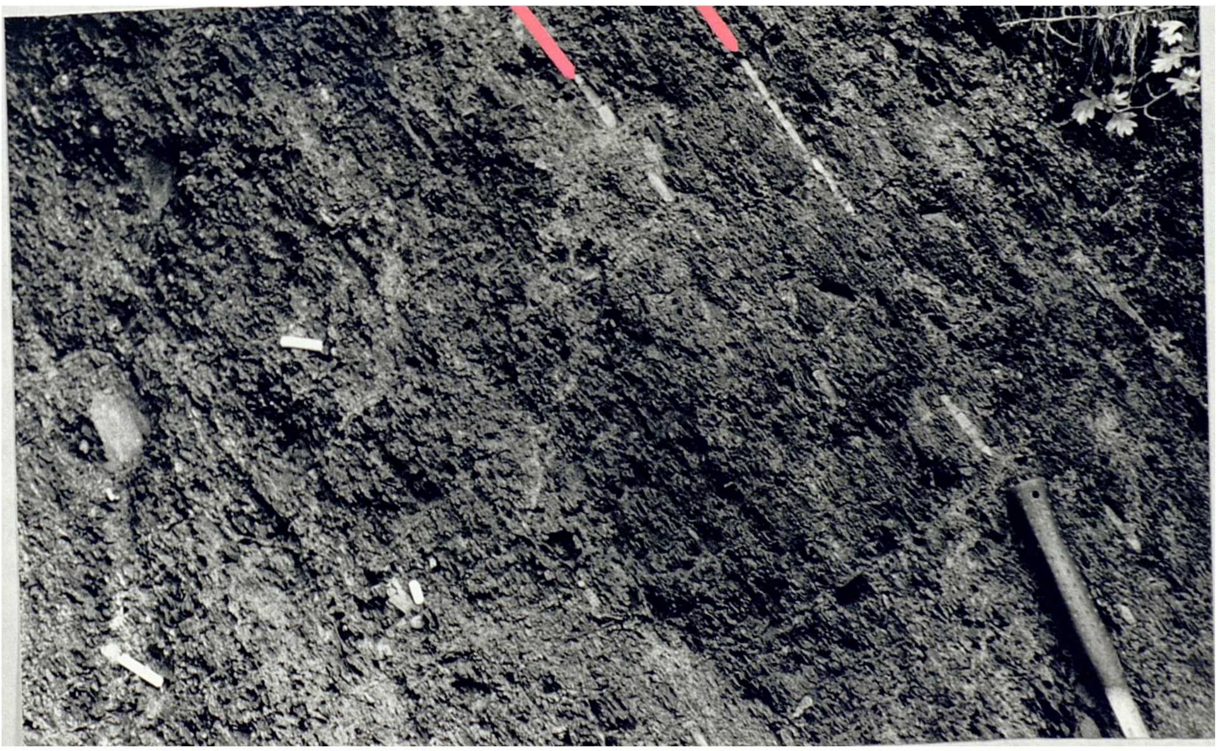


Plate 13

Lithofacies 8, Trough Cross Laminated Sandstone with gradational base in Pule Hill Grit sequence (Interdistributary Bay with Minor Mouth Bar Sands) of Holmbridge Woodhouse Quarry (SE 129064, level 11.6-14.6m, Fig 81; 1m tape length is exposed).

Plate 14

Same as plate 13, except that a greater upper part of the Pule Hill Grit vertical sequence in Holmbridge Woodhouse Quarry is involved (Level 13.9-20.1m, Fig. 81; 0.80m tape length is exposed).

Plate 15

Parallel Laminated Thicklip bedded Siltstone unit (turbidite deposits in an overbank setting) within the Scotland Flags Mudstone in Rake Dike (SE 098051; level 4-15m, c sequence, Fig 12). Siltstone unit is rich in ichnogenera <u>Olivellites</u> and <u>Pelecypodichnus</u> as shown in Plates 126A and B. Note the gradational base of the siltstone beds. Hammer is 33cm long.

Plate 16

Tabular interbeds of lithofacies 6, Siltstone and 2, Unfossiliferous Mudstone (Intermediate depth Mouth Bar) of the Hazel Greave Grit in Sunny Bank Cutting) (SD 788194; level 4-15m, c sequence, Fig 12). Note the remarkable regular appearance of the interbeds and the upward increase in Siltstone bed thickness (Compare siltstone thickness within the lengths of the lower and the upper tapes (arrowed); 0.50m of the lower tape and 1m of the upper tapes are exposed.

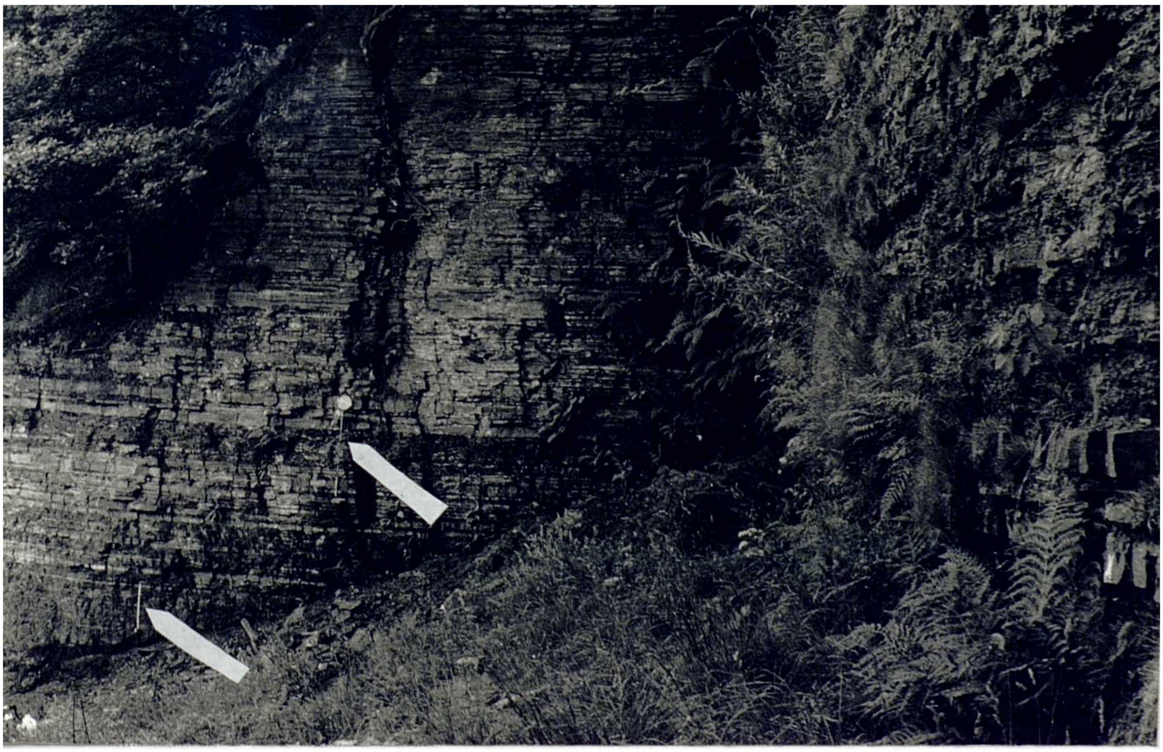


Plate 17

Convolute bedding (arrowed) in Lithofacies 6, Siltstone (Bay deposit) within the Pule Hill Grit of Fletcher Bank Quarry (level 35.8m, central vertical section of Fig 59). Note the sharp base of Channel 4 at top.

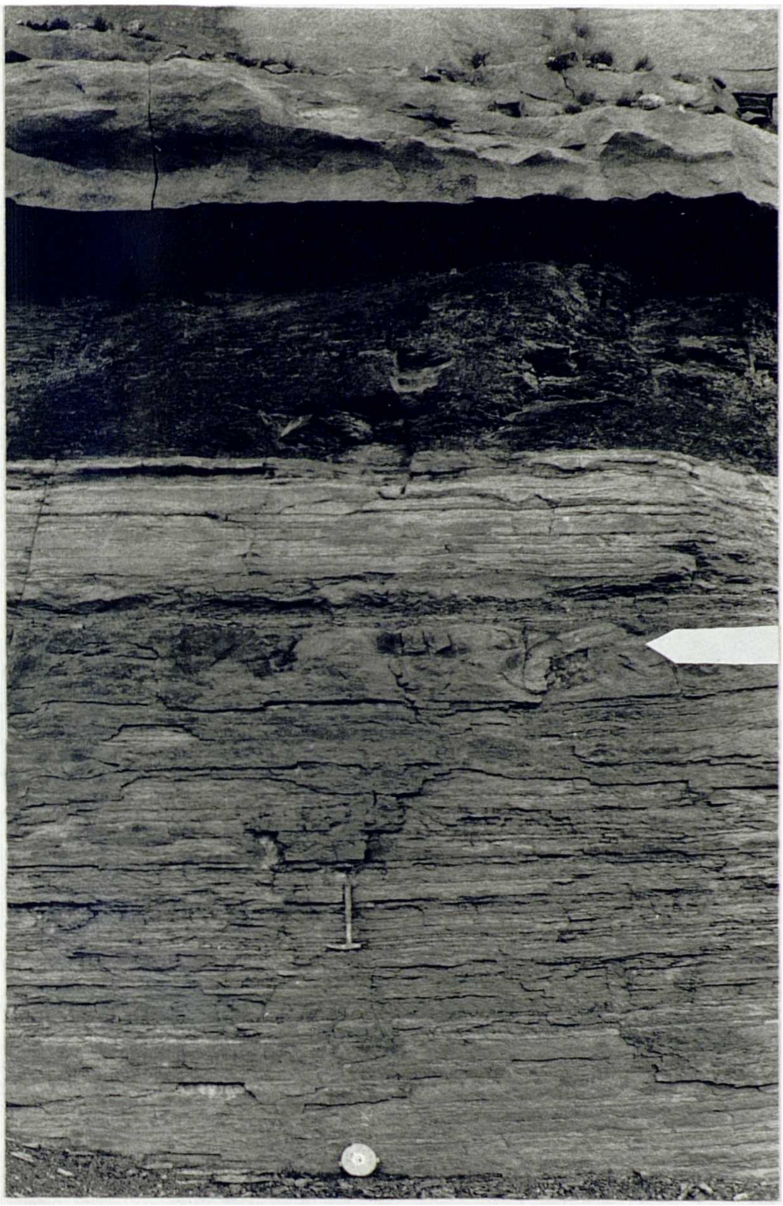


Plate 18.

Slumped and unslumped Horizons. (Density current deposits within the Slope Association) occurring in the Hazel Greave Mudstone of Longworth Valley Exposure (SD 689157), level 2-22m, Fig 29). Figure 30 is a traced sketch of this plate and shows the positions of the bands of R. bilingue lote, R. metabilingue and R. superbilingue. Note the positions of plates 19, 20 and 21. Man on ladder is 1.5m tall.

Plate 19.

Close up photograph of the slump layer at the south parts of plate 18. Figure 31 is a trace of this plate and shows the positions of the interpreted thrust planes thought to have brought several limbs of many folds in close contact with one another. Chalk limes outline the stratification within siltstone layer. Hammer is 33cm long.

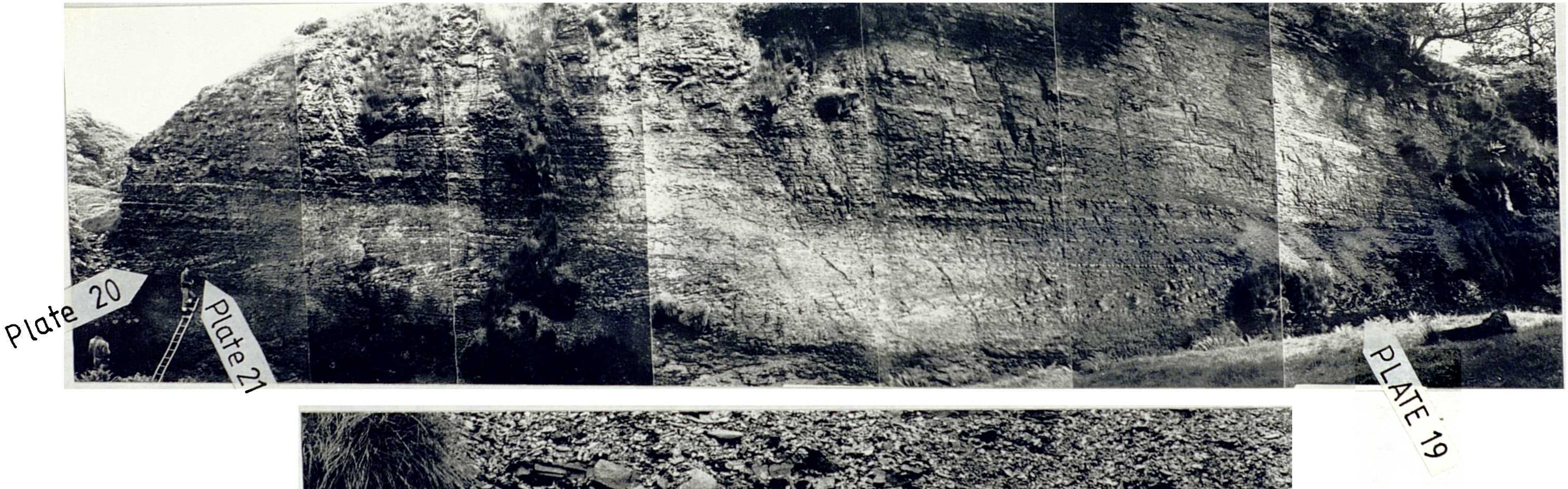


Plate 20
Plate 21
PLATE 19

Plate 20

Close up photograph of the slump layer in the north parts of plate 18. The emphasis of this plate in on the single *contorted bed affected.* Man on ladder is 1.5m tall. Note the position (arrowed) of plate 21. (See plate 18 and Fig. 30 for the position of this plate).

Plate 21

Close up photograph of the middle part of Plate 21 showing the lower curving upward part (X) of the major fold (See plate 18 and Fig 30 also for the position of this plate). Diameter of ten pence piece is 29mm.


X of Plate 21

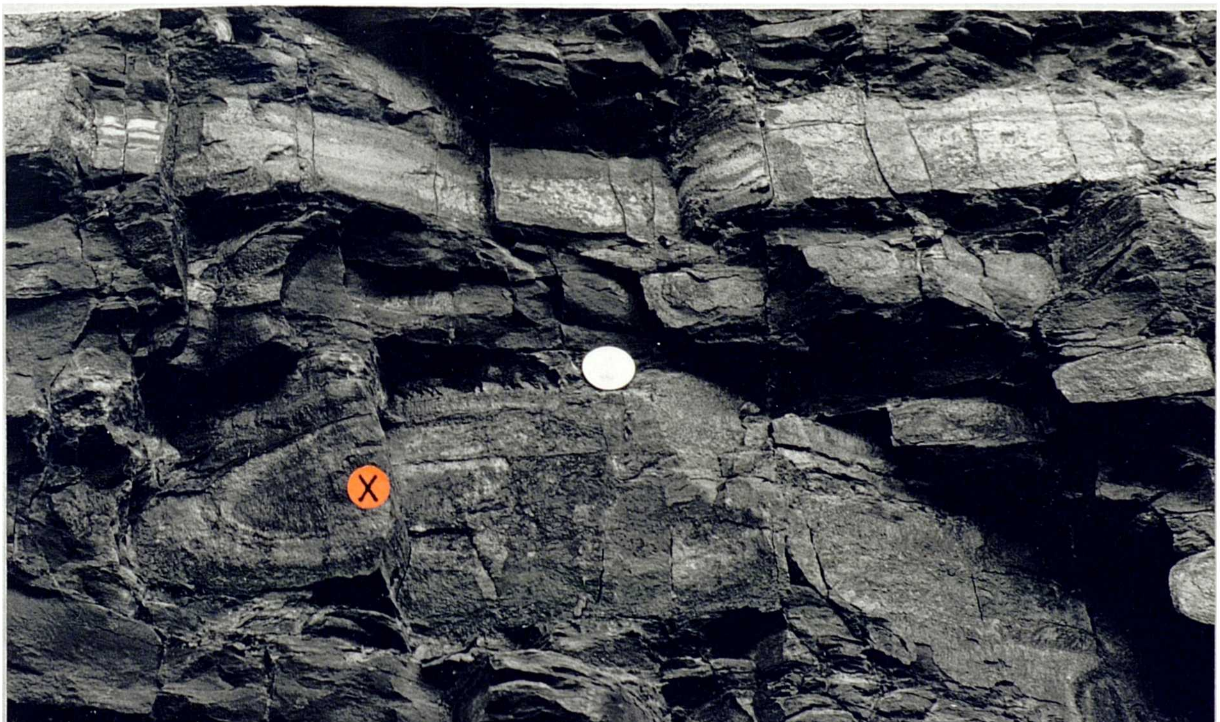

X

Plate 22

Connected lenticles (arrowed) in lithofacies 7, rippled silty sandstone (Grevasse splay) in the Pule Hill Grit of Fletcher Bank Quarry (SD 805165, level 32m, Central Vertical Section, Fig 59). One penny piece is 20mm in diameter.

Plate 23.

Climbing ripples in lithofacies 7, Rippled Silty Sandstone, (Levee sequence) in the Pule Hill Grit of Harper Clough Section (SD 717316), level 4.5m, Fig 78B). Pencil is 15cm long.

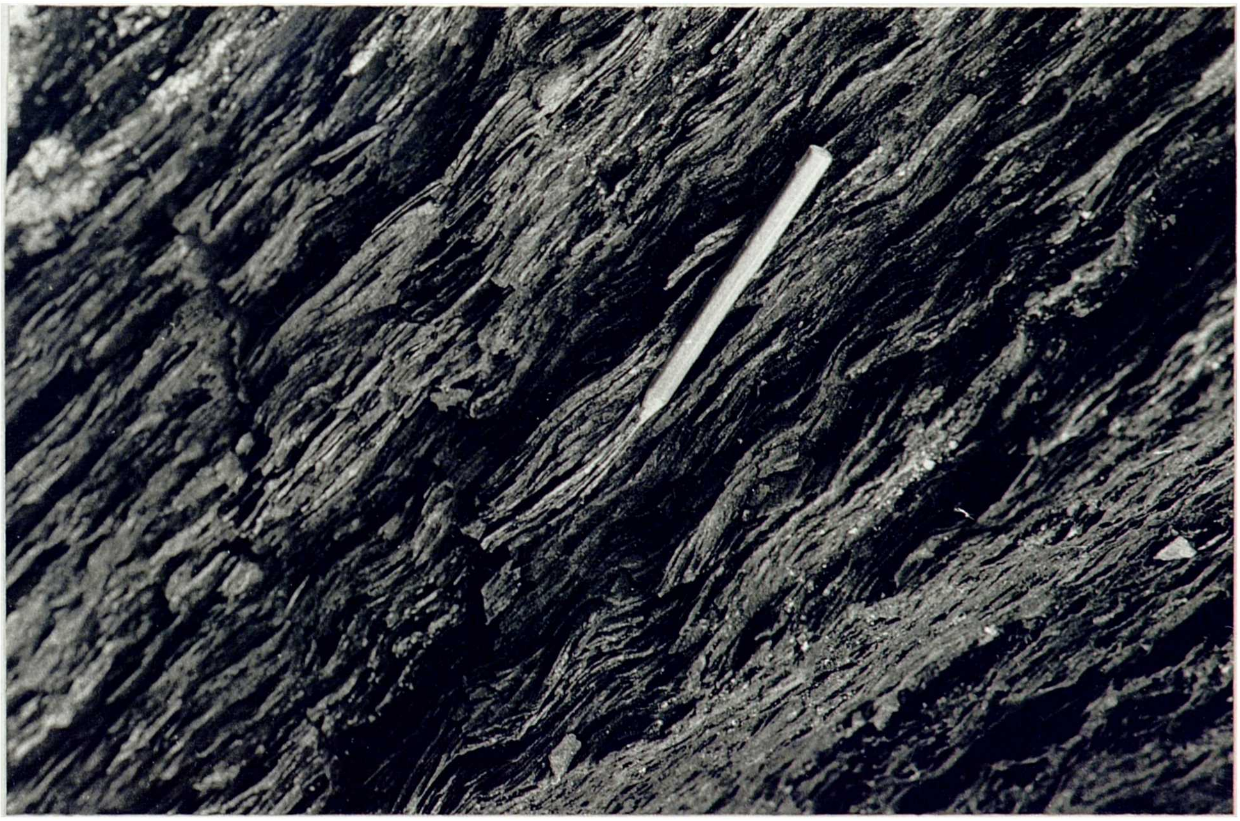


Plate 24

Symmetrically wave-rippled top of lithofacies 8, Trough Cross Laminated Sandstone (Levee Sequence) in the Pule Hill Grit of Harper Clough section (SD 717316, level 4.2m, Fig 78B). Colour marker is 13cm long.

Plate 25

Sandstone lenticles of lithofacies 7, rippled silty sandstone, (Grevasse splay) "floating" in siltstone layer of the Pule Hill Grit in Fletcher Bank Quarry (SD 805165, level 33.5m, Central Vertical Section, Fig 59). One penny piece is 20mm in diameter. Arrows mark levels of the most distinct lenticles.


750
BROAD LINE PERMANENT

Plate 26

Siltstone layer, Lithofacies, as parting (arrowed) between lithofacies 7, Rippled Silty Sandstone Grevasse splay) of the Pule Hill Grit in Fletcher Bank Quarry (SD 805165,level 34m, Central Vertical Section, Fig 59). One penny piece is 20mm in diameter.

Plate 27

Crescentric pattern of Lithofacies 8, Trough Cross Laminated Sandstone (Mouth Bar) of Pule Hill Grit in plan view, Heyden Road (SE 097035, level 13.9m, Fig 56).

Plate 28

Lithofacies 10, Trough Cross Bedded Sandstone (few are arrowed) as transverse intraset (falling water stage feature) of angular Foresets in Hazel Greave Grit of Wicking Crag Quarry (SE 049374, level 60m, "b" sequence, Fig 15). Figure 35 is a traced sketch of parts of this plate and shows the relationship between the intraset and the foresets. Compass lies on the base of the cross-bedded set. Ten pence piece is 29mm in diameter.

Plate 29

Destruction of the stratification of lithofacies 8, Trough Cross Laminated Sandstone (Grevasse Channel) of the Pule Hill Grit by Pelecypodichnus in Warland Wood Quarries (SD 948203, level 26.3m, Fig 24). Tape is 5cm long.

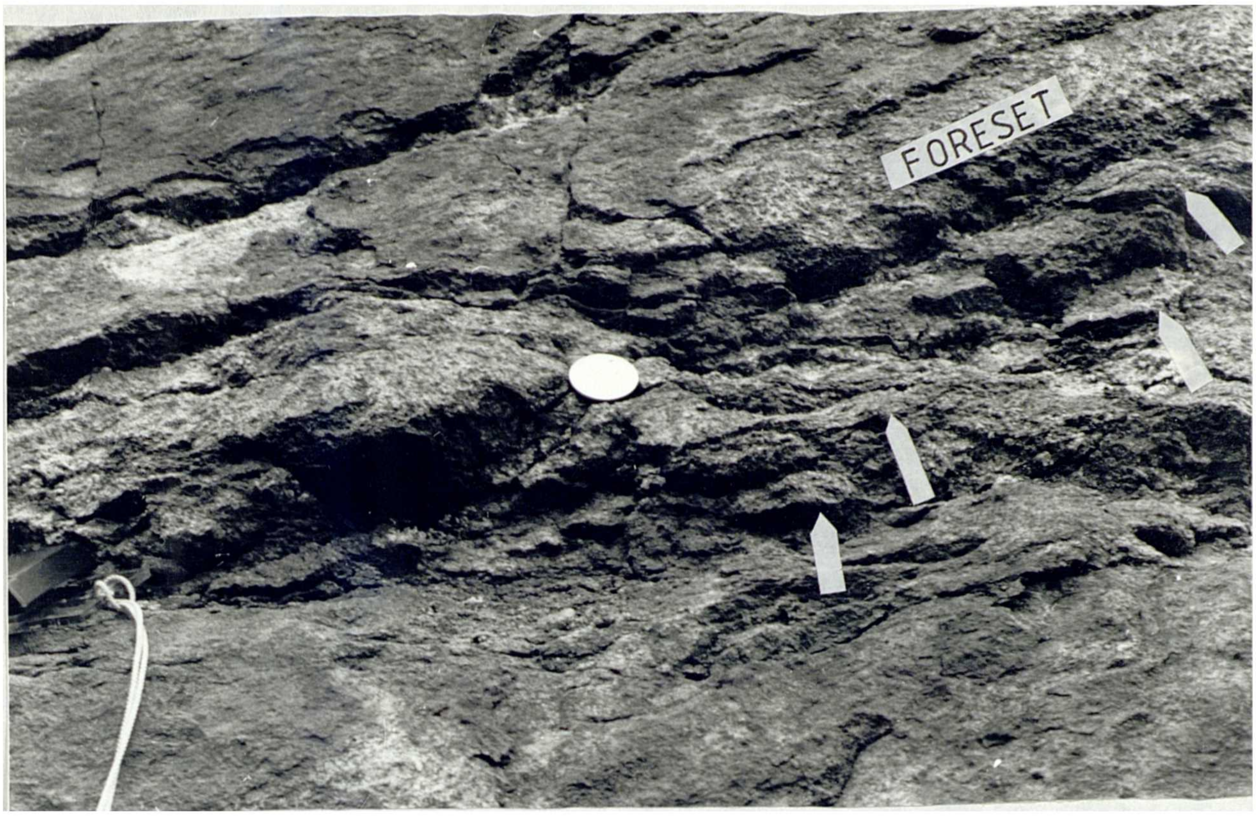

FORESET

Plate 30

Lithofacies 9, Parallel Laminated Sandstone in Scotland Flags (Mouth Bar area) of the Scotland Quarries (SE 033268, level 4m, Vertical Section 1, Fig 55). Note dark and light coloured band accentuating lamination.

Plate 31

Ball and Pillow structure in the Pule Hill Grit (Mouth Bar) of Light Hazzles Clough (SD 956193). Hammer is 33cm long.

0 30 cm

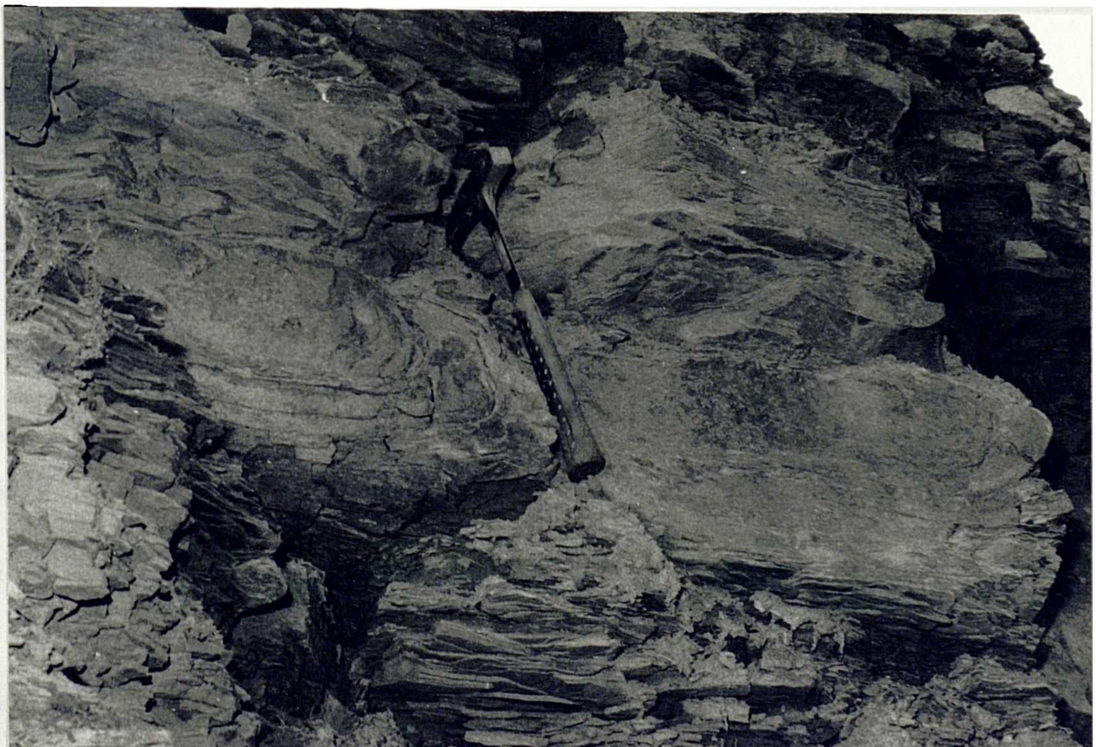


Plate 32

Pebbles in Lithofacies 10, Trough Cross Bedded Sandstone, (Channel) of the Pule Hill Grit in Braithwaite Quarry (SE 040418). One penny piece is 20mm in diameter.

Plate 33

Mud Conglomerates and Plants in Lithofacies 10, Trough Cross Bedded Sandstone (Channel) of the Pule Hill Grit in Ponden Clough (SD 980363, level 66m, 'f' sequence, Fig 17). Tape reel is 4cm and two pence piece (arrowed) is 27mm in diameter.

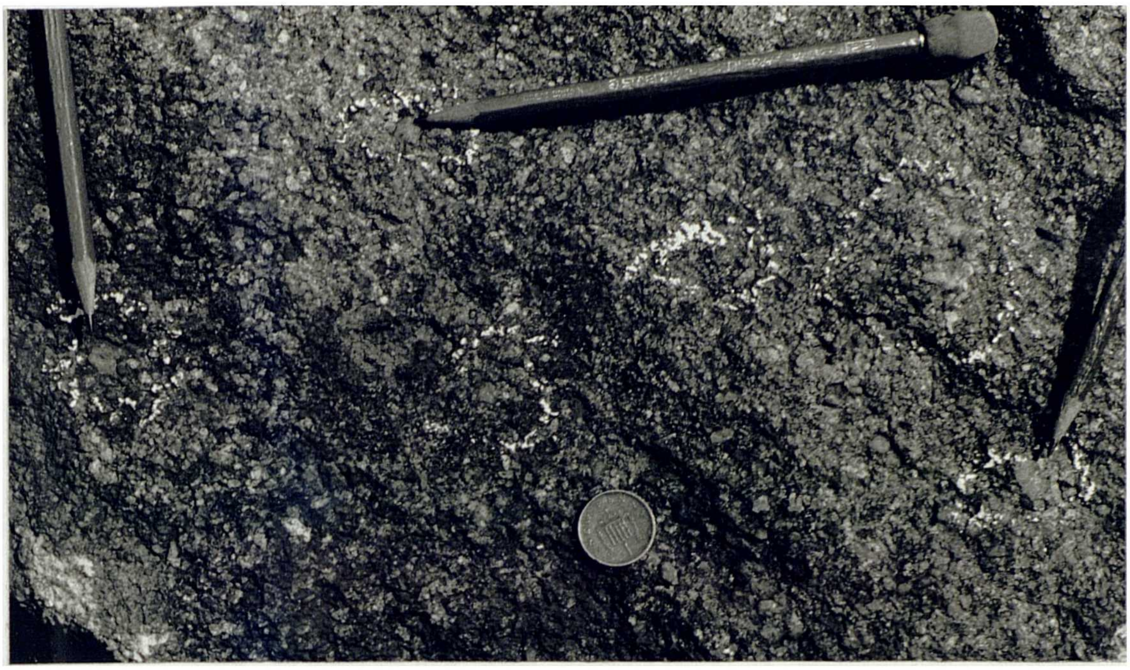


Plate 34

Logs of Wood in Lithofacies 10, Trough Cross Bedded Sandstone (Grevasse Channel) in the Pule Hill Grit sequence in Woodhouse Quarry (SE 062397), level 7m, Fig 82). Arrow points to structure resembling scrabble mark.

Plate 35

Planar laterally extensive boundary surfaces of Lithofacies 10, Trough Cross Bedded Sandstone (Mouth Bar Area) in the Pule Hill Grit Sequence of Park Wood Quarry (SE 067406, level 45m, 'd' sequence, Fig 15). Hammer (arrowed) is 33cm long.

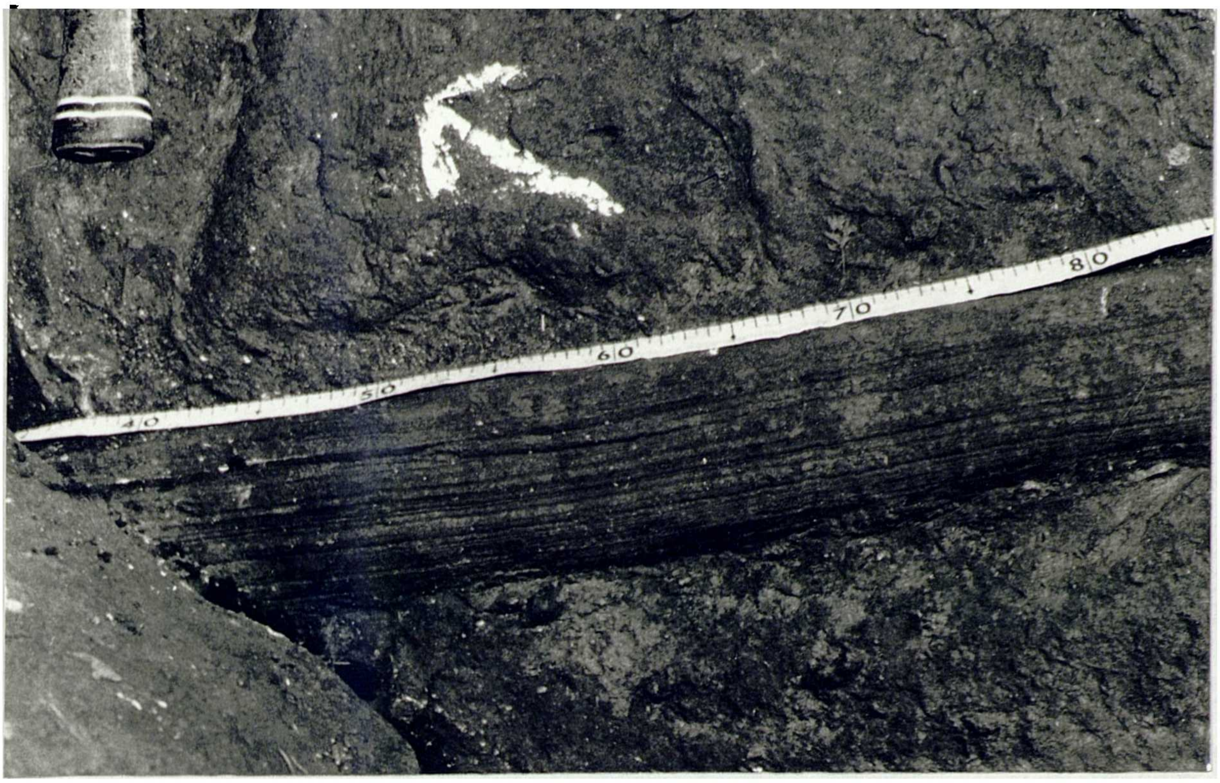
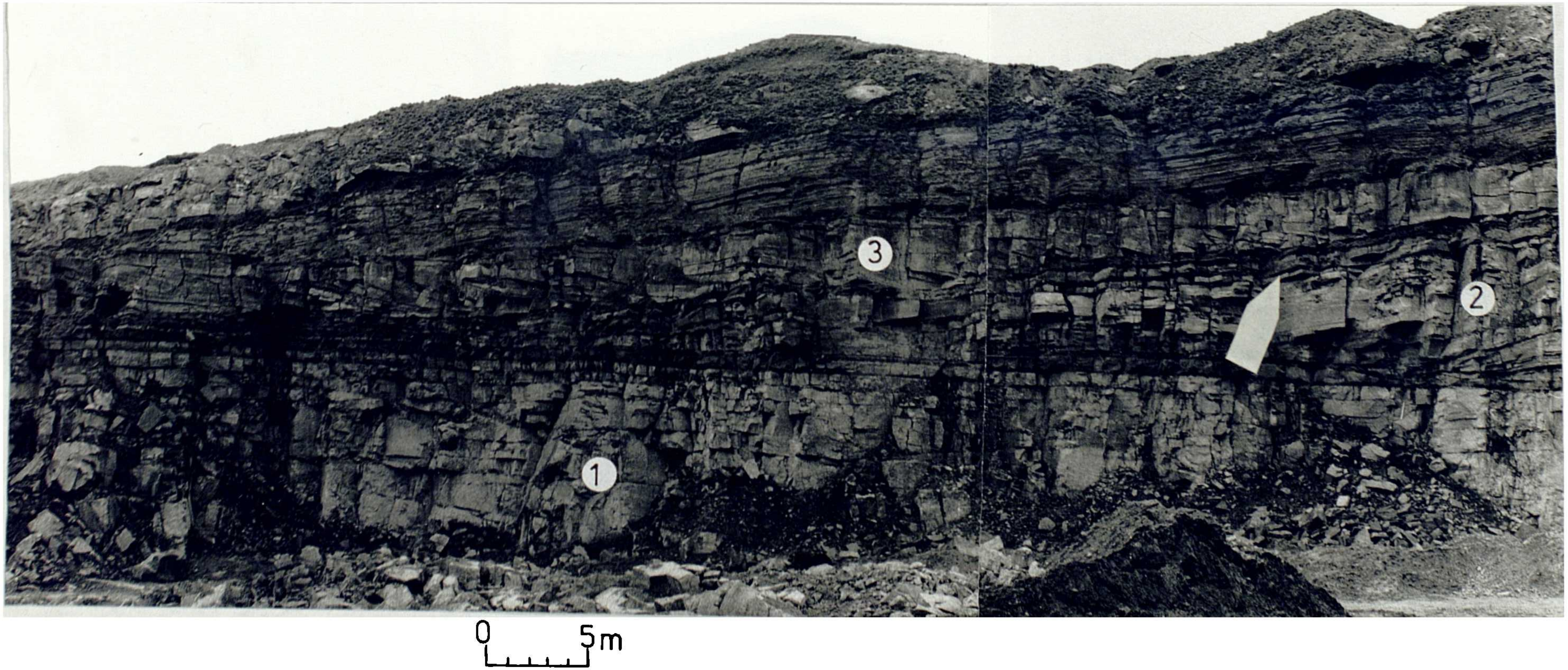

40
50
60
70
80

Plate 36

Concave upward Lower erosive bases of Lithofacies 10, Trough Cross Bedded Sandstone (Mouth Bar) in the Hazel Greave Grit of Clough Road Exposure (SE 083157). Tape is 1m long.

Plate 37

Set boundaries of lithofacies 10, Trough Cross Bedded Sandstone (Distributary channel) of the Pule Hill Grit gently dipping in a direction roughly perpendicular to the true palaeocurrent trend (arrowed)in Channel No. 2 of Fletcher Bank Quarry (SD 805165) 1,2,3 denote channels 1,2,3 as shown in Figure 59.



1
2
3
0 5m

Plate 38

Sinuous Dunes at the top of the Pule Hill Grit (Levee) in Harper Clough Quarry (SD 717316, level 15.3m, Fig 78B). Note the concave closures of set margin. Hammer 33cm long.

Plate 39A

East-West Section of the Pule Hill Grit (Distributary Channel or Mouth Bar) in Branshaw Quarry (SE 031402, level 10m, 'a' sequence, Fig 15) showing indirectional planar foresets (Note position of tape reel which is 17cm in diameter).

Plate 39B

Northeast-southwest view of the same section shown in plate 39A (use tape reel for overlap), here portraying trough cross-stratification. Tape reel is 17cm in diameter.

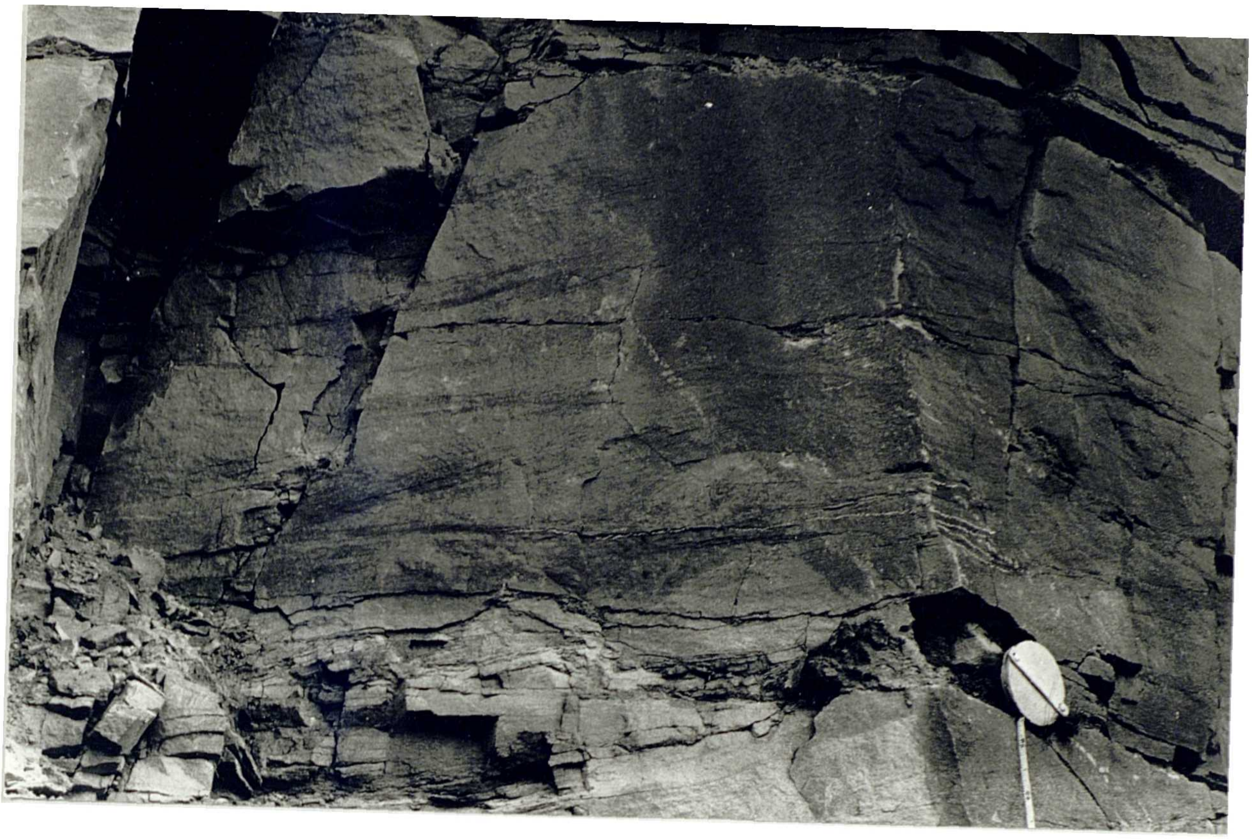


Plate 40.

Tree trunk in growth position in Pule Hill Grit (Levee) of Harper Clough Quarry (SD 717316, level 15.3m Fig 78B). Note the symmetrical arrangement of the roots. Hammer is 33cm long.

Plate 41.

Close up of Plate 40 around Hammer to show the pitted internal structure of the roots. Hammer is 33cm long.

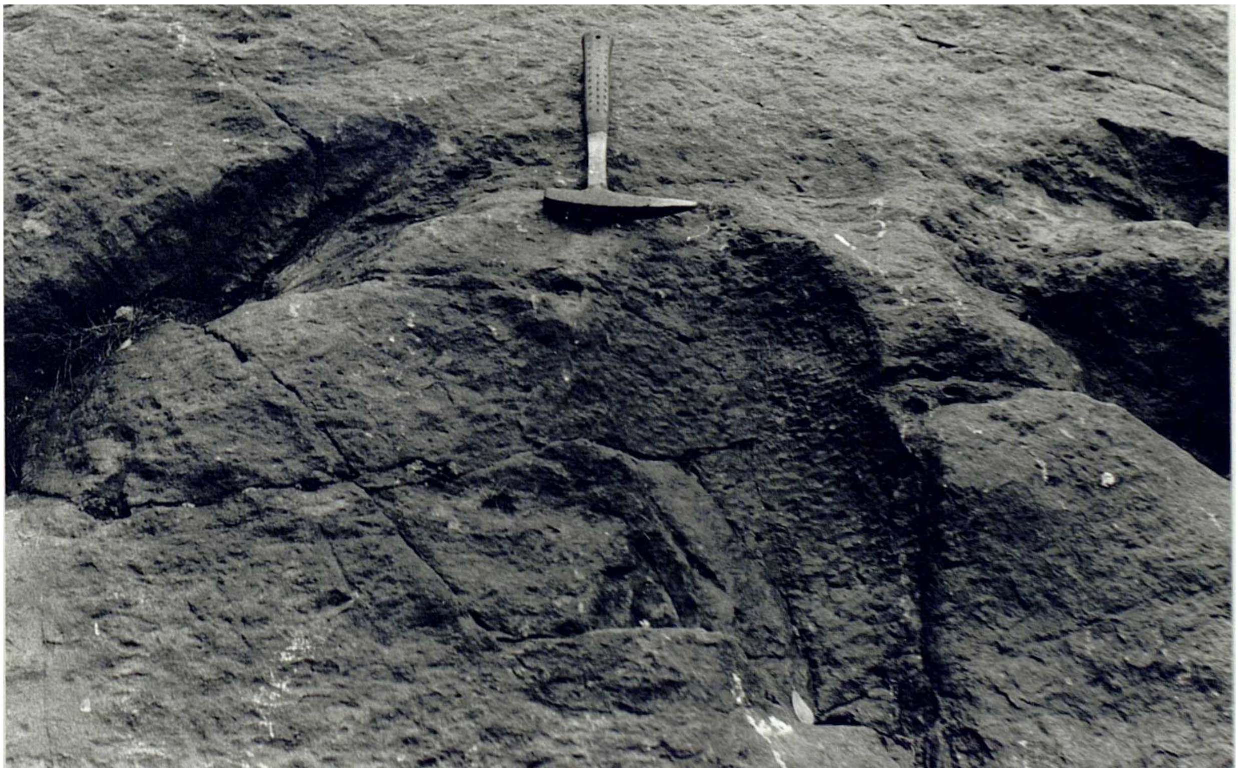


Plate 42.

Co-existence of lithofacies 10, Trough Cross Bedded Sandstone and 11, Tabular Cross Bedded Sandstone in Pule Hill Grit (Distributary Channel) type section SE 032106, Hammer is 33cm long.

Plate 43.

Log of wood in lithofacies 11, Tabular Cross Bedded Sandstone (Distributary Channel 1) in Pule Hill Grit of Fletcher Bank Quarry (SD 805165, level 2.3m Northern Vertical Section, Fig 59).

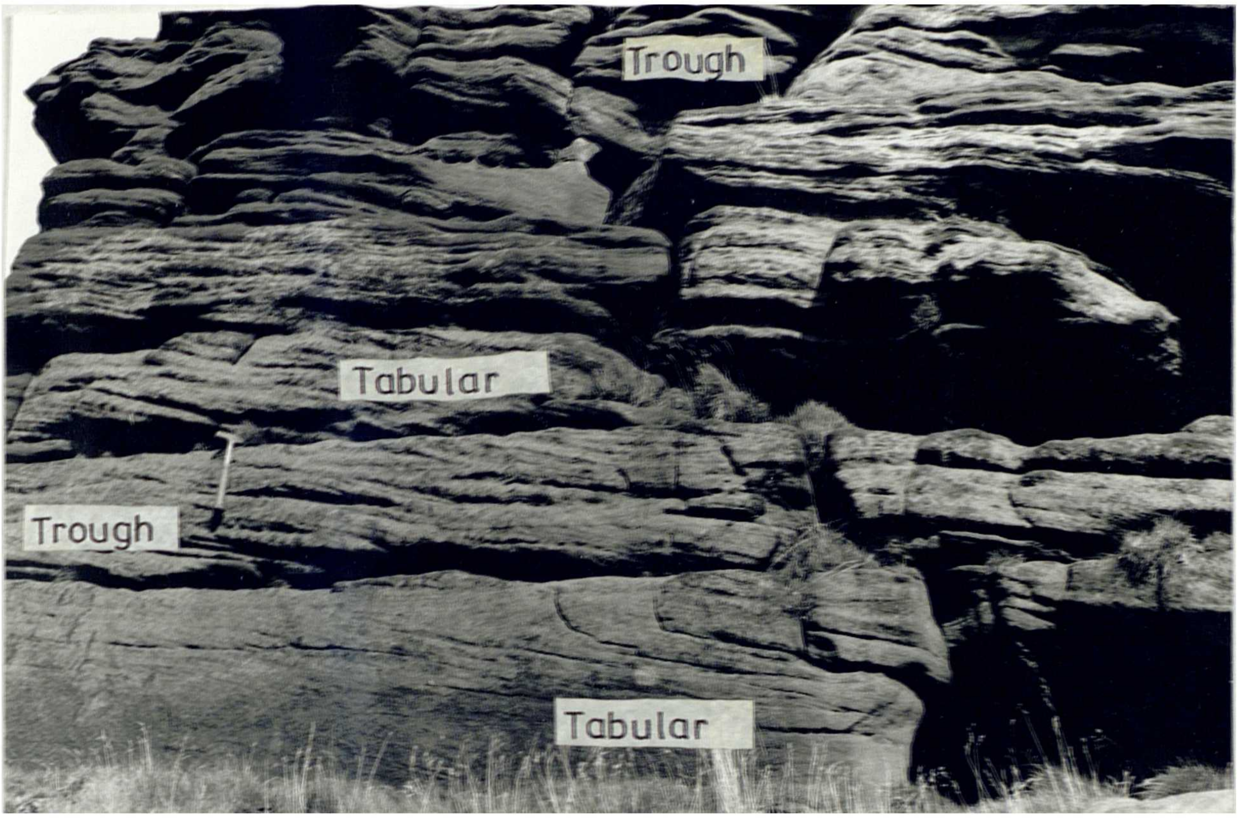

Trough
Tabular
Trough
Tabular

Plate 44

Angular foresets of Lithofacies 11, Tabular Cross Bedded Sandstone (Distributary Channel) in Pule Hill Grit sequence of Buckden Clough (SD 789188, level 16m, Fig 79). Hammer (arrowed) is 33cm long.

Plate 45.

Tangential Foresets of Lithofacies 11, Tabular Cross Bedded Sandstone (Distributary Channel) in Scotland Flags of Triangle Railway Cutting (SE 047224). Hammer (arrowed) is 33cm long.

Plate 46

Concave upward Foresets in lithofacies 11, Tabular Cross Bedded Sandstone (Distributary Channel) in Hazel Greave Grit in Esholt Junction Railway Cutting (SE 193413), near Guiseley.

Plate 47

Mud clasts aligned with their long diameter parallel and along the cross bedding planes in Hazel Greave Grit (Distributary Channel) of Bracken End Quarry (SE 194433) near Guiseley. Tape reel is 5cm long. Note chalk marks along cross bedding planes.

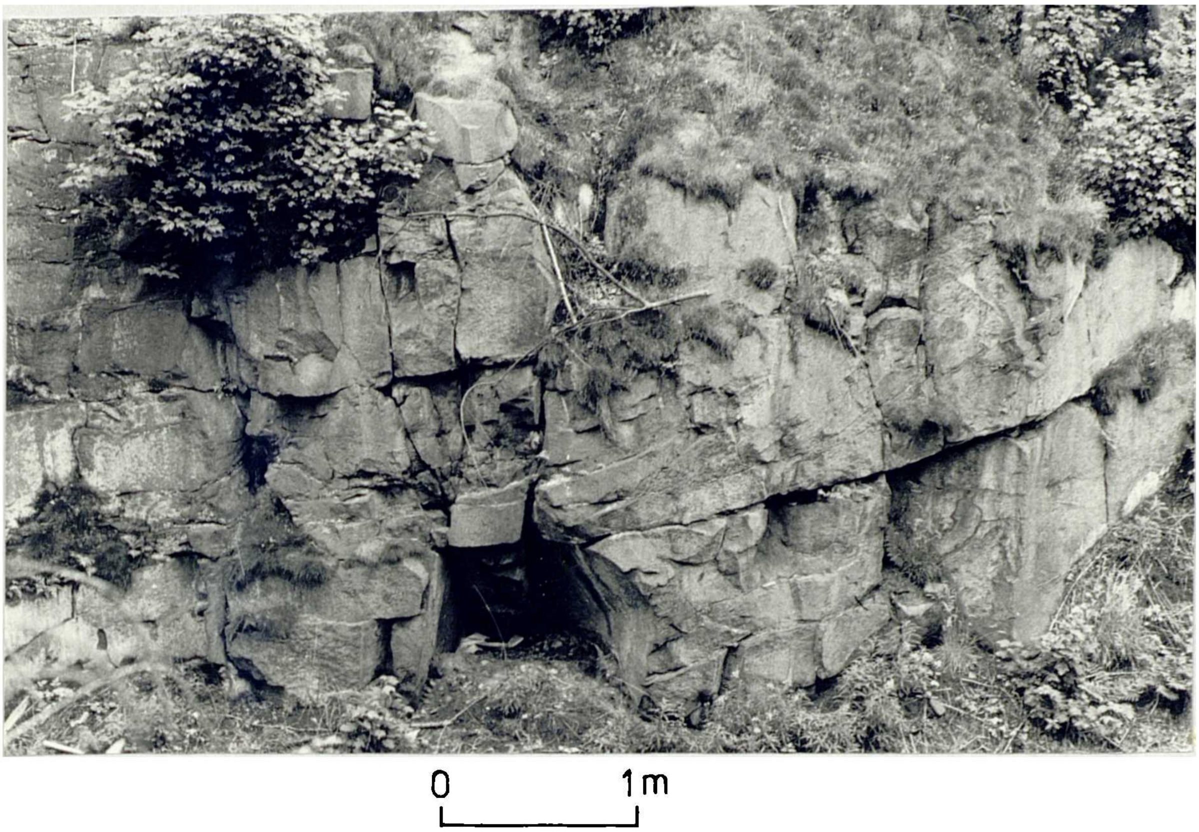
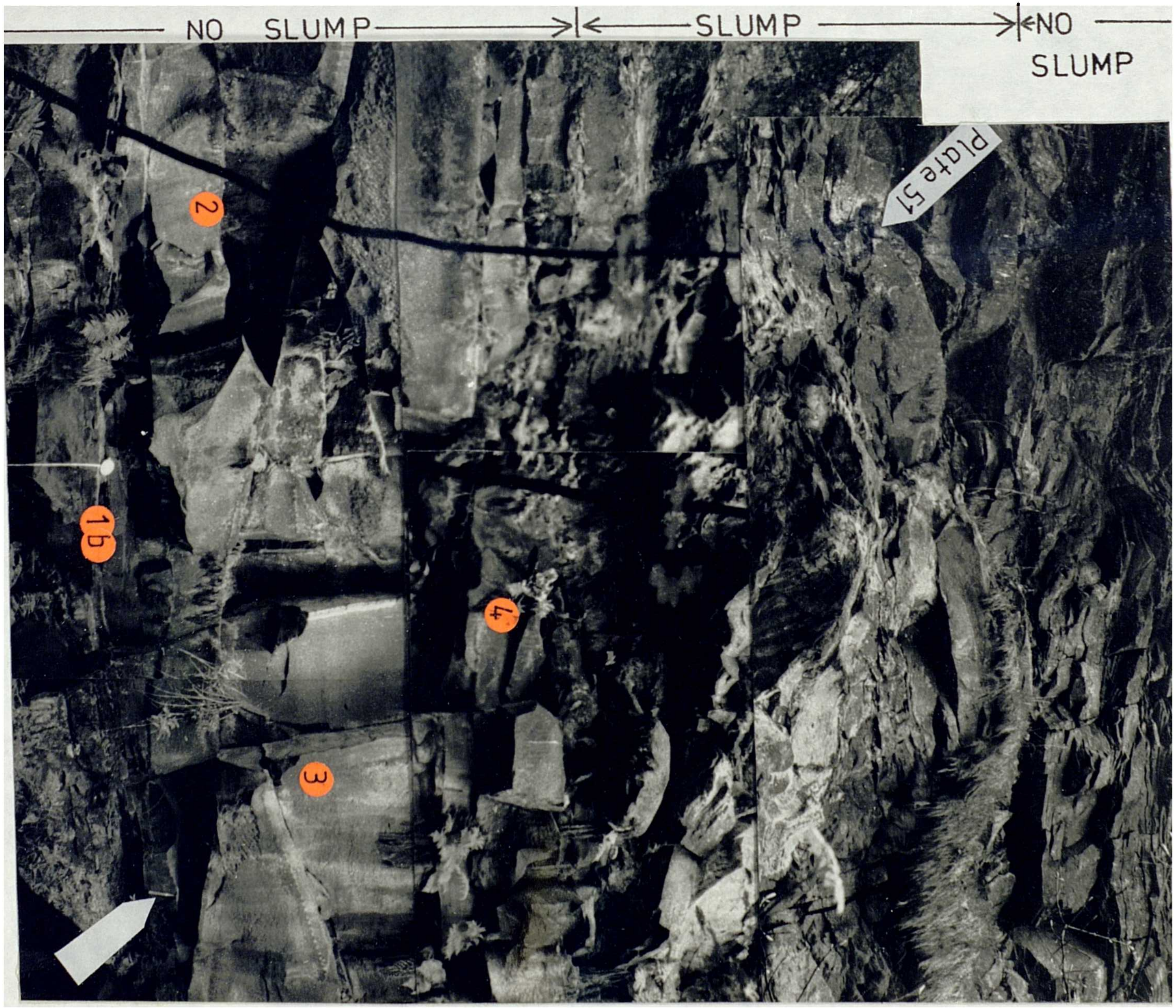

0
1m

Plate 48

Low angle foresets of lithofacies 11, Tabular Cross Bedded Sandstone (Distributary Channel) in Scotland Flags of Triangle Railway Cutting (SE 047224). Hammer (arrowed) is 33cm long. Note the extensive length of each foreset.

Plate 49

Slumped and unslumped Units (Distributary Channels) in the Scotland Flags exposed in the middle 15m parts of Riverside Cemetery Quarry, (SE 053237), Sowerby Bridge. The unslumped lower zone is occupied by Lithofacies 13, Scour based Sand bodies 1b, 2, 3, 4 (Siee Fig 37 for the outlined trace of each of these sand bodies and other details of this plate. Plate 65 is from the lower unslumped zone). Use hammer (arrowed, 33cm long) or tape 1m for scale. Note the position of plate 51.



NO SLUMP
SLUMP
NO SLUMP
Plate 51
2
1b
4
3

Plate 50

Partly deformed climbing ripples, in the slumped zone (Distributary Channel) in the Scotland Flags exposed at the southwest end of Riverside Cemetery Quarry (SE 053237), Sowerby Bridge. (This plate is the southwest lateral equivalent of the slumped zone of plate 49). Note the gently inclined folds (arrowed) of the unit. Hammer 33cm long.

Plate 51

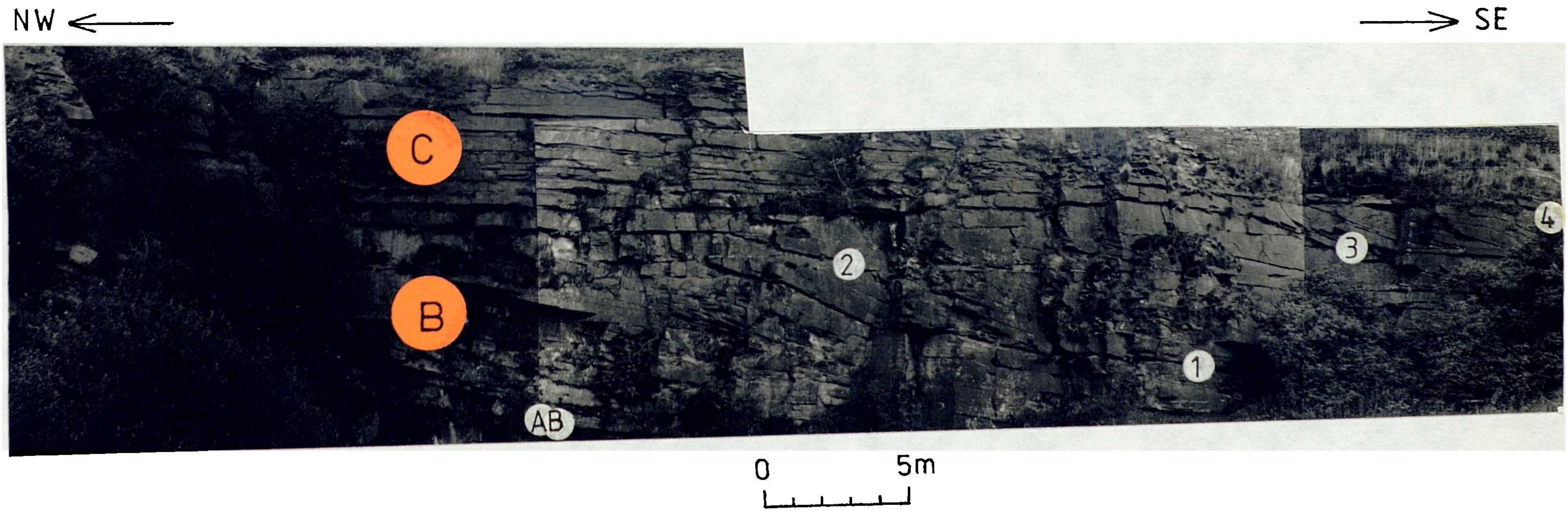
Overturned and recumbent folds in the slumped Scotland Flags (Distributary Channel) exposed in the middle 15m parts of Riverside Cemetery Quarry (SE 053237). See the position of plate 51 in plate 49. Hammer 33cm long.

Plate 52

Inclined folds (arrowed) in the slumped Scotland Flags (Distributary Channels) exposed at the southwest end of Riverside Cemetery Quarry (SE 053237) Sowerby Bridge. Hammer (pointed at by chalk-marked arrows) is 33cm long.

Plate 53

Lithofacies 12, Large Scale Cross-Bedding with Concave upward foresets (in B). Low-Angle foresets, denoted by letter A in Figure 42, which is a trace of this plate, is not conspicuous in this plate. Note the sandy mudstone drape (AB; Plate 57 is a picture of this drape), the internal erosion surfaces 1, 2, 3, 4 and the grading southeastwards of Lithofacies 14, Horizontal Bedded Sandstone (C), into lithofacies 12, Large scale Cross Bedded Sandstone (A, B, C are Scotland Flags distributary channel units in Diggley Quarry, SE 110094, near Holmfirth).



NW
SE
C
B
AB
2
1
3
4
0
5m

Plate 54

Lithofacies 12, Large Scale Cross Bedding (Distributary Channel) of the Pule Hill Grit in Tower Hill Side (SD 906263, 15-27m 'f' sequence. Fig 16. Tape 1m for scale) overlain by Lithofacies 10, Trough Cross Bedded Sandstone. Rock soil sits on internal erosion surface.


Tape 1m

Plate 55

Lithofacies 12, Large Scale Cross Bedding (Subasqueous levee in Mouth Bar Area) with Concave upward foresets - Pule Hill Grit in Dark Wood Quarry 3, (SE 067406, level 62m, 'd' sequence, Fig 15. Hammer 33cm for scale.

Fig. 56

Lithofacies 12, Large Scale Cross Bedding (Subaqueous Levee in Mouth Bar Area) with concave upwards foresets and finer-grained gradational bases. Pule Hill Grit in Park Wood Quarry 2 (SE 070409).

0 40 cm

Plate 57

Sandy Mudstone drape in Lithofacies 12, Large Scale Cross Bedding (Distributary Channel) of Scotland Flags in Diggley Quarry (SE 110094). Cap 28cm in length is in the drape. Note that this plate is a close-up picture of 'AB' of plate 53.

Plate 58

Sigmoidal foresets (F layer) in the Pule Hill Grit of Kebroyd Quarry (SE 040210), Distributary Channel). Hammer 33cm long is looked on the asymptotic lower part of the most distinct sigmoidal foreset. Sigmoidal layer is overlain erosionally (arrowed) by Lithofacies 10, Trough Cross Bedded Sandstone. All units.

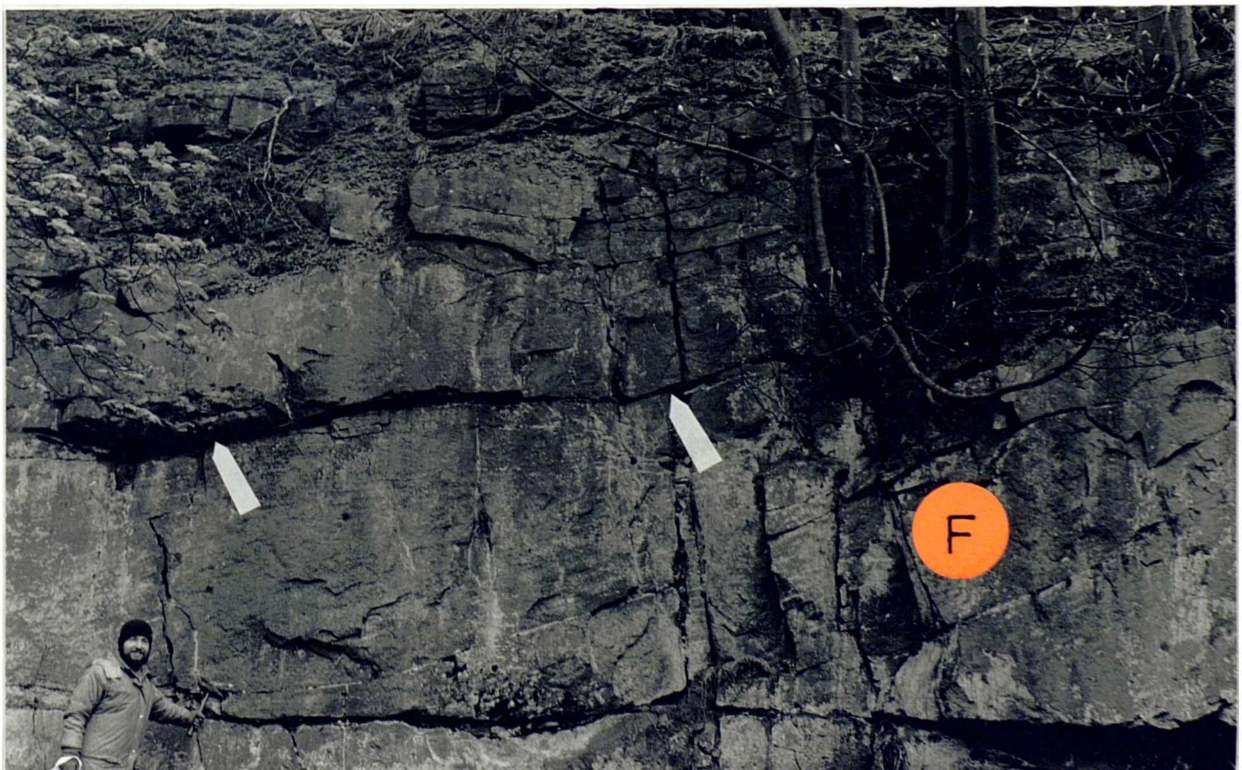

F

Plate 59

Internal erosion surface (E) in the Pule Hill Grit (Distributary Channel) is Ramsden Clough (SE 121038).

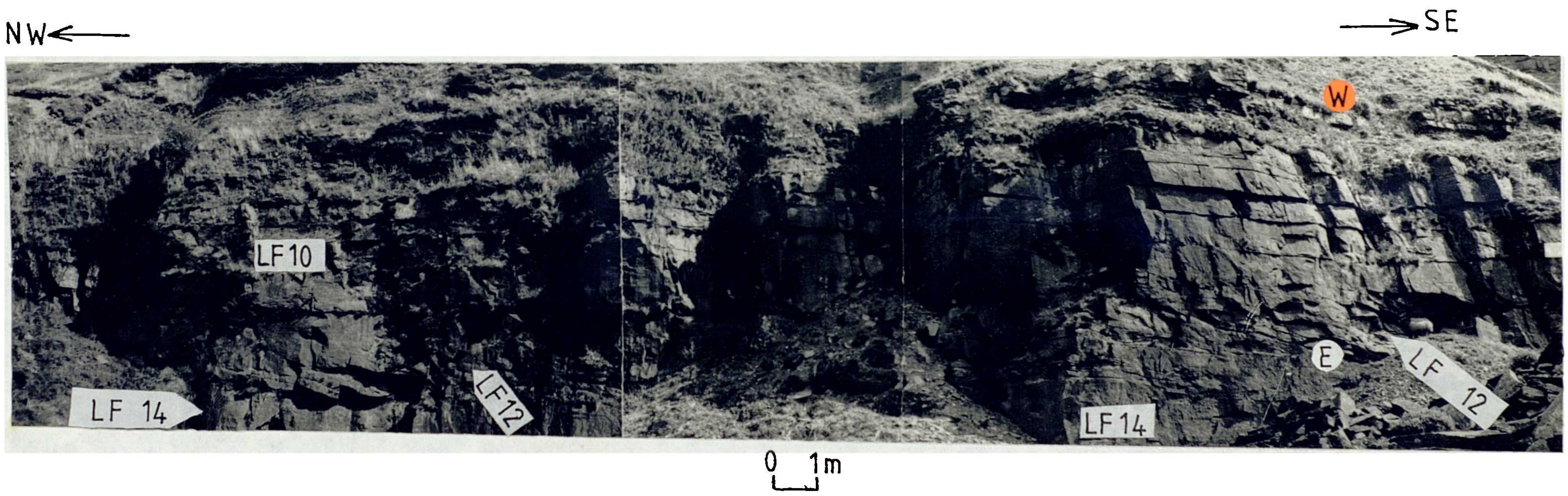

E
0
1m

Plate 60

NW-SE Face of Quarry in Ramsden Clough. showing southeaterly gradation of Lithofacies (LF) 10, Trough Cross Bedded Sandstone, to Lithofacies (LF) 12, Large Scale Cross Beds. Note internal erosion surface "E" truncating its underlying cross beds (See Fig 43, which is a traced sketch of this plate for fuller details of the relationships between the cross beds. (SE 121038, Pule Hill Grit Channel sediments in level 80-90m, 'd' sequence , Fig 12. Plate 60 is the Northwest one-third of the overall Quarry Exposure in Ramsden Clough of which plates 61 and 62 are part of).

Plate 61

The same quarry as in Plate 60 but represents the central one-third of the overall quarry exposure in Ramsden Clough. Internal erosion surface 'E' is the southeast continuation of the 'E' in plate 60. Note, the lenticular beds which overlie 'E' directly; the overlapping behaviour of the undulatory foreset (arrowed) in a southeast direction. Figure 44 is a traced sketch of plate 61.


NW
SE
LF 10
LF 14
LF12
W
E
LF 12
LF14
0 1m

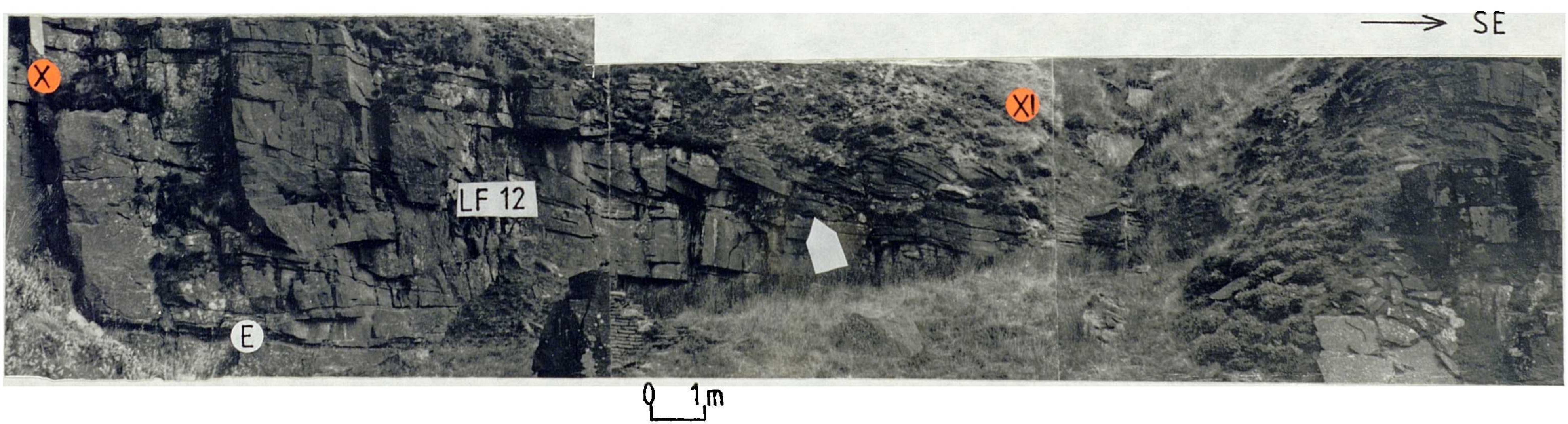

SE
X
XI
LF 12
E
0 1m

Plate 62

The same quarry as in plates 60 and 61 but represents the southeast one-third of the overall quarry exposure in Ramsden Clough. Note the internal erosion surface 'EE' truncating its underlying cross beds, and the overlapping behaviour of the foresets in a southeast progression. Figure 65 is a traced sketch of Plate 62.

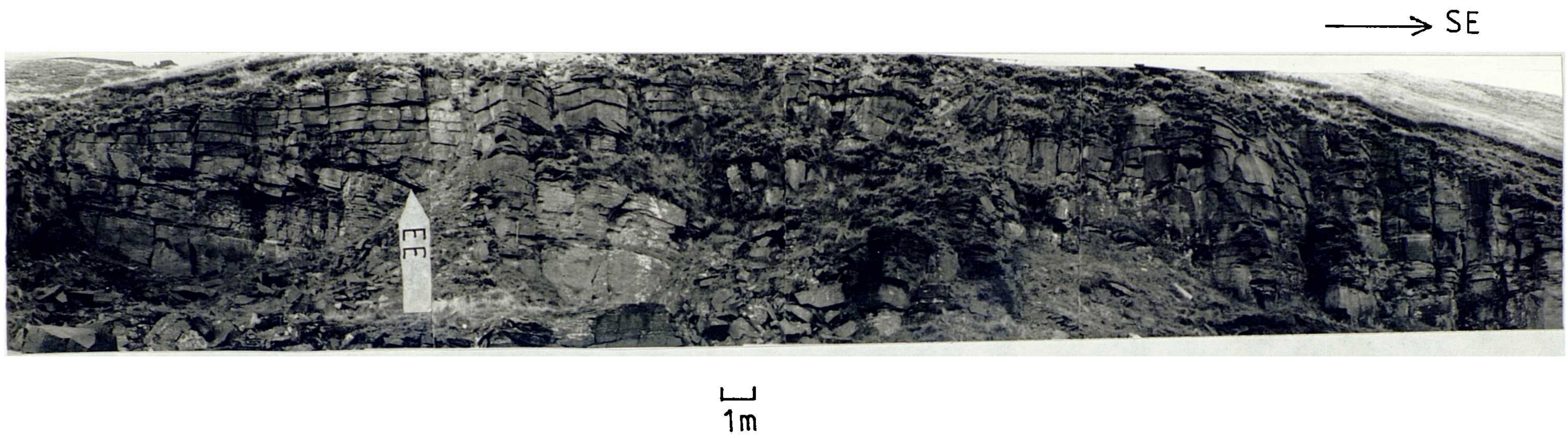

SE
EE
1m

Plate 63

Close up photograph of southeast parts of Plate 60 and northwest two-thirds of Plate 61 (Use the notations 'WXX1' in plates 60, 61 and 63 for overlap and comparison) showing clearer details of internal erosion surface 'E',Lenticular beds (arrowed) and lithofacies (LF) 12, Large Scale Cross Bedding.

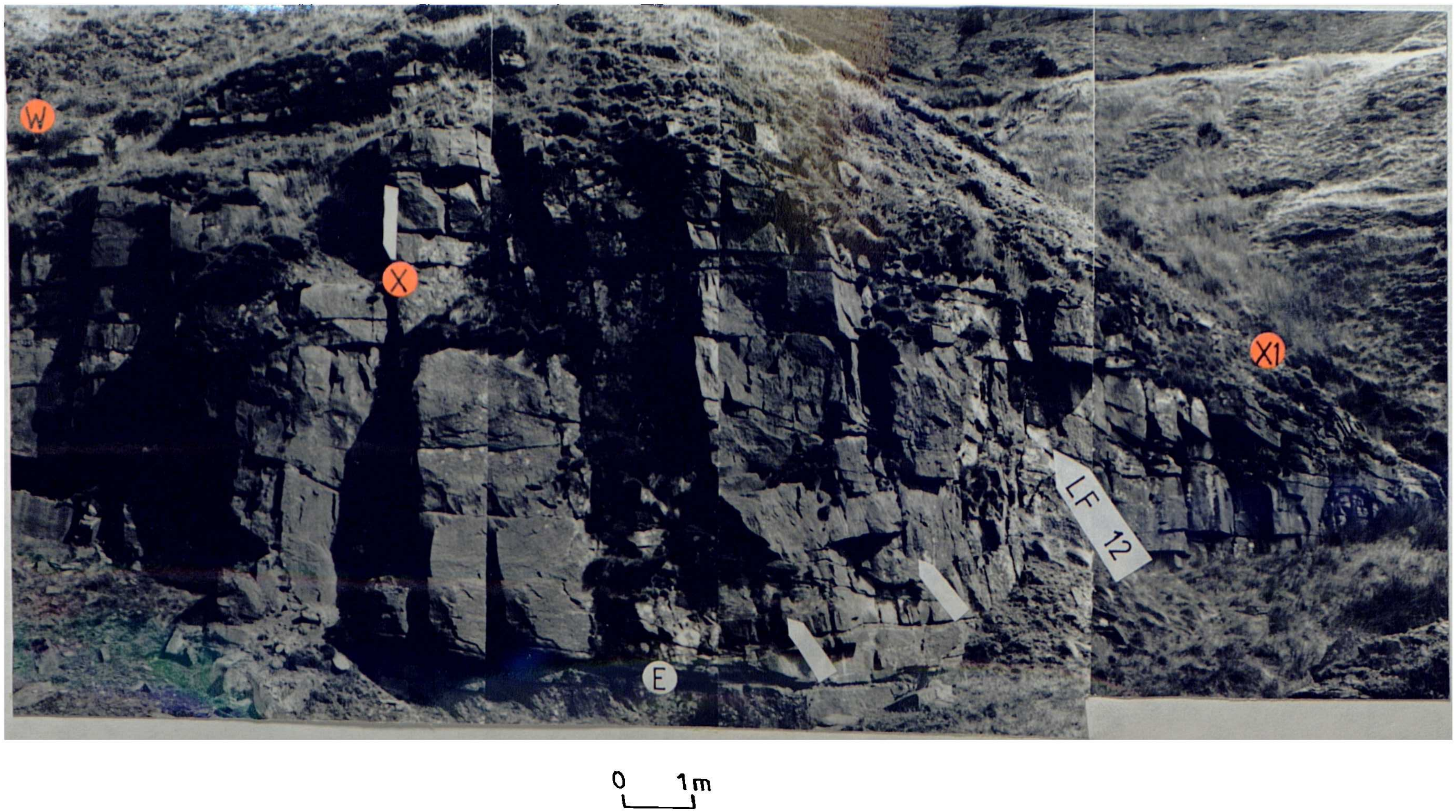

W
X
X1
LF 12
E
0
1m

Plate 64

Scour based sand body (Distributary Channel) of the Hazel Greave Grit in Wicking Crag (SE 052372, level 60m, 'b' sequence Fig 15). Tape is 1m long and tape reel sits on sand body top.

Plate 65

Scour based sand body (A, Distributary Channel) in Scotland Flags in Riverside Cemetery Quarry (SE 053237), Sowerby Bridge. Note-book, 20cm long, lies on the truncated top of sand body 'A'. Note relief of scour of the base of 'B'.


PL.64

PL. 65

Plate 66

Log of wood at base of Scour based sand body (Distributary Channel) of Hazel Greave Grit in Tower Hill Side (SD 906261, level 47m, 'f' sequence, Fig 16). Chalk marked scale at sandstone base is in cm.Marker is 11cm long.

Plate 67

Log of wood (arrowed) at base of Scour based sand body (Distributary channel) in Hazel Greave Grit in Wicking Crag (SE 052372, level 59m, 'b' sequence, Fig 15). Tape reel is 17cm in diameter.

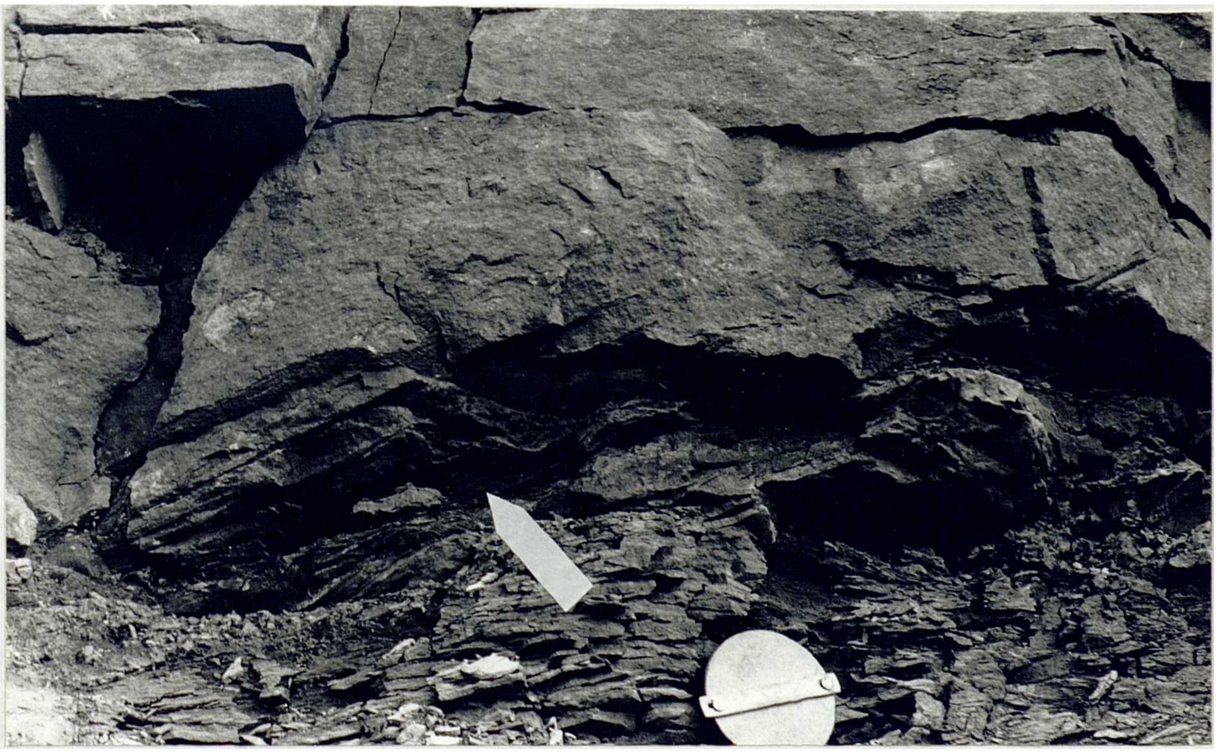


Plate 68

Quartz and mud conglomerate at the base of scour based sand body (Distributary Channel) of Hazel Greave Grit in Tower Hill Side (SD 906261, level 47m, 'f' sequence, Fig 16). Marker, 11cm long, lies within one of the holes previously occupied by a mud clast. Hammer is 33cm long.

Plate 69

Mud conglomerates at base of scour based sand body (Distributary Channel) of Hazel Greave Grit in Gorpley Clough (SD 914234,level 95m, 'g' sequence, Fig 16). Compare the diameter of the ten pence piece (arrowed, 29mm) with those of the mud conglomerate.

Plate 70

Thin shale and coalified wood (arrowed), occurring in between two scour based sand bodies of Hazel Greave Grit (Distributary Channel) in Wicking Crag (SE 052372, level 59m, 'b' sequence, Fig 15). Hammer is 33cm long. Base of sand body 'A' is rich in ichnogenus *Phycodes curvipalmatum* and plates 99 and 100 were derived from this base.

Plate 71

Coalified wood (arrowed, Lag concentrates), at the base of Scour based sand body (Distributary Channel) of Hazel Greave Grit in Tower Hill Side (Plate 71 is from the same rock face and level as in plate 66). Hammer is 33cm long.


A
Plates 99 & 100
Shale

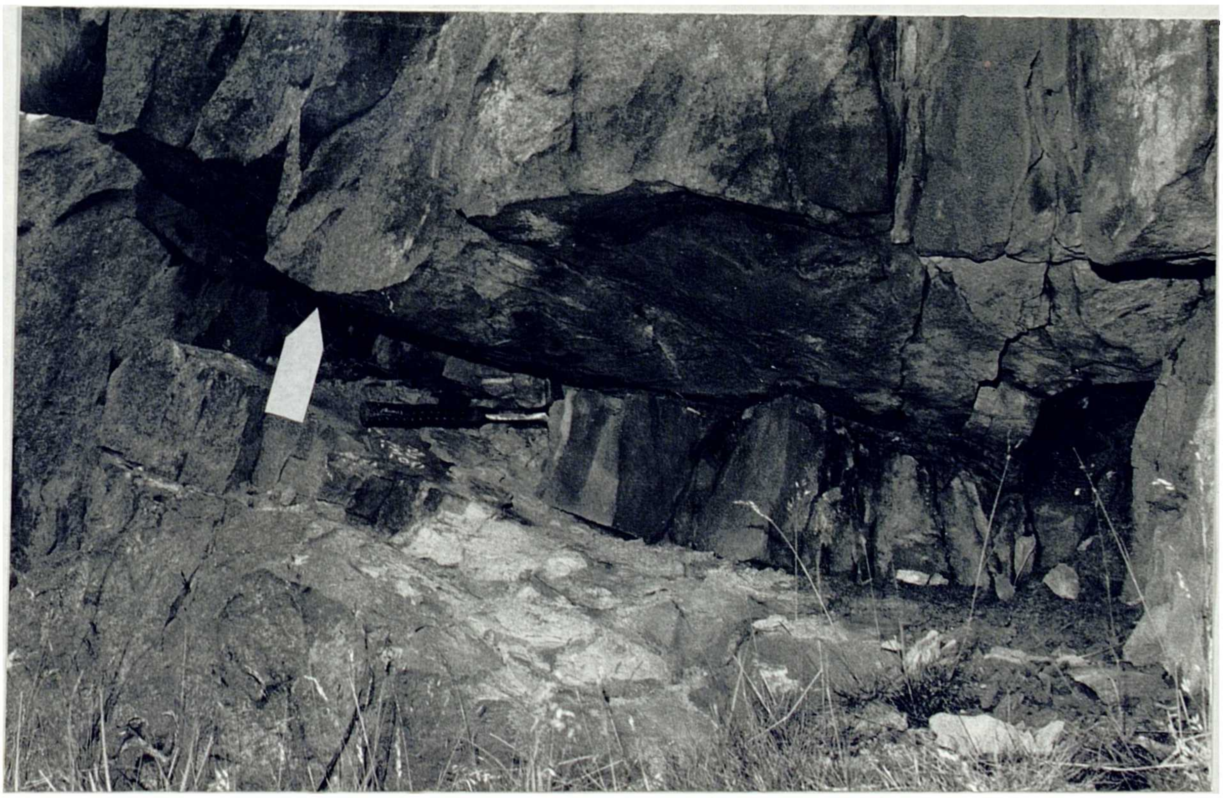


Plate 72

Symmetrical cross-strata of Scour based sand body (Distributary Channel) in Scotland Flags sequence in Riddesden Quarry (SE 068430). Note the concordance between the lower bounding surface and the cross-strata (See plate 76A for the position of plate 72 in relationship to Plate 76A).

Plate 73

Scour based sand bodies (Channels) in North-South face of Pule Hill Grit type section. Figure 47 is a traced sketch of Plate 73 and should be referred to for an appreciation of the concordance of the cross-strata to the lower bounding surface of each of the three sand bodies A, B, C (Channels; SE 032106). Note the location of Plate 8, and the location and trend of Plate 77 (arrow at South end of plate).

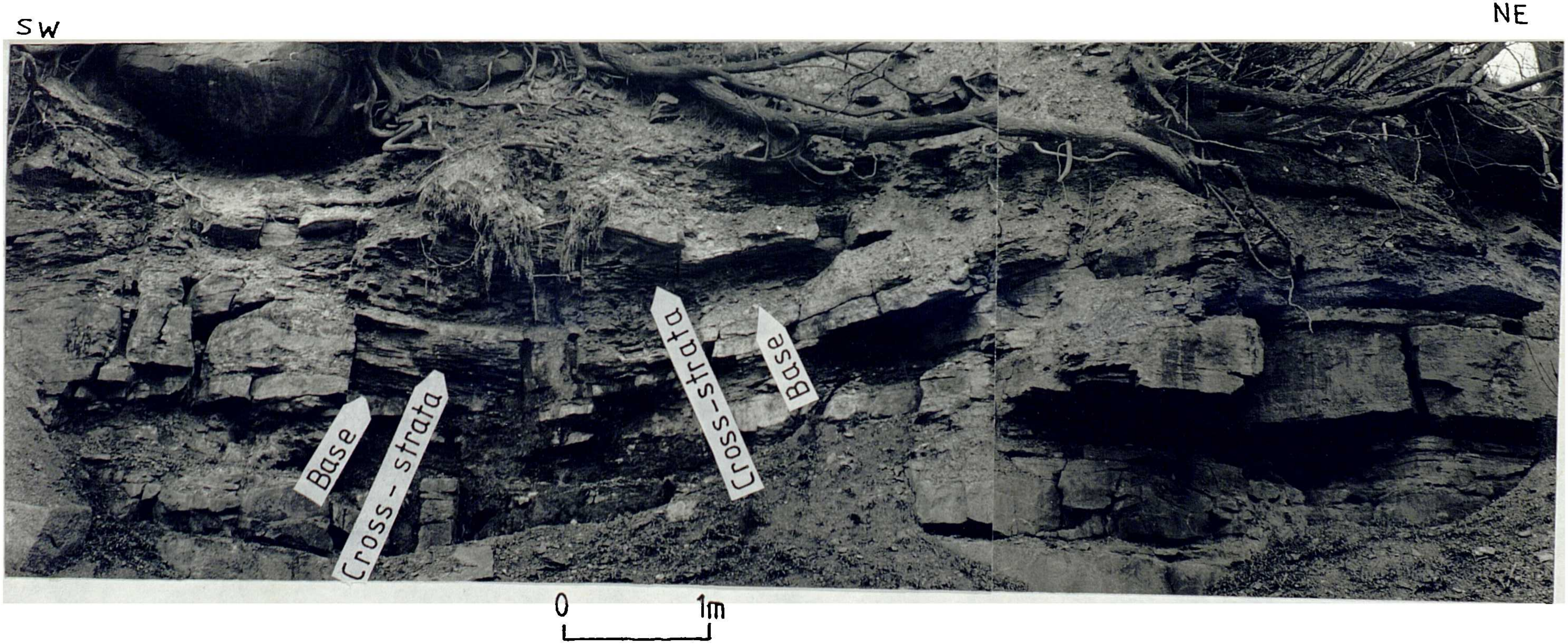


PLATE 8

Plate 74

Almost the same photograph as in plate 65, but taken from a different position to emphasise the concordance of the cross beds (A) to its lower bounding surface (arrowed). Notebook is 20cm long. Note relief of scour of overlying sand body.

Plate 75

Cross beds (B) discordant to the lower bounding surface (arrowed) of Scour based sand body (Channel) in the Pule Hill Grit sequence of Fletcher Bank Quarry. (SD 805165, level 34m, Northern Vertical Section, Fig. 59A. See 6 in Fig 59B for the position of Plate 75 in plan within the Fletcher Bank Quarry area. Hammer (H) is 33cm long.


A
A


B
H

Plate 76A

Northeast-southwest face of the Scotland Flags Quarry in Riddlesdon (SE 068430) showing scour based sand bodies A, B and C (Distributary Channels). Note the interest of lithofacies 10, Trough Cross Bedded Sandstone (I), in A and B. Cross-strata within C are concordant to the lower bounding surface. (See the area around S). Man, 1.5m tall, places his right hand on the boundary between A and B. Note the position of plate 72.

SW ← → NE

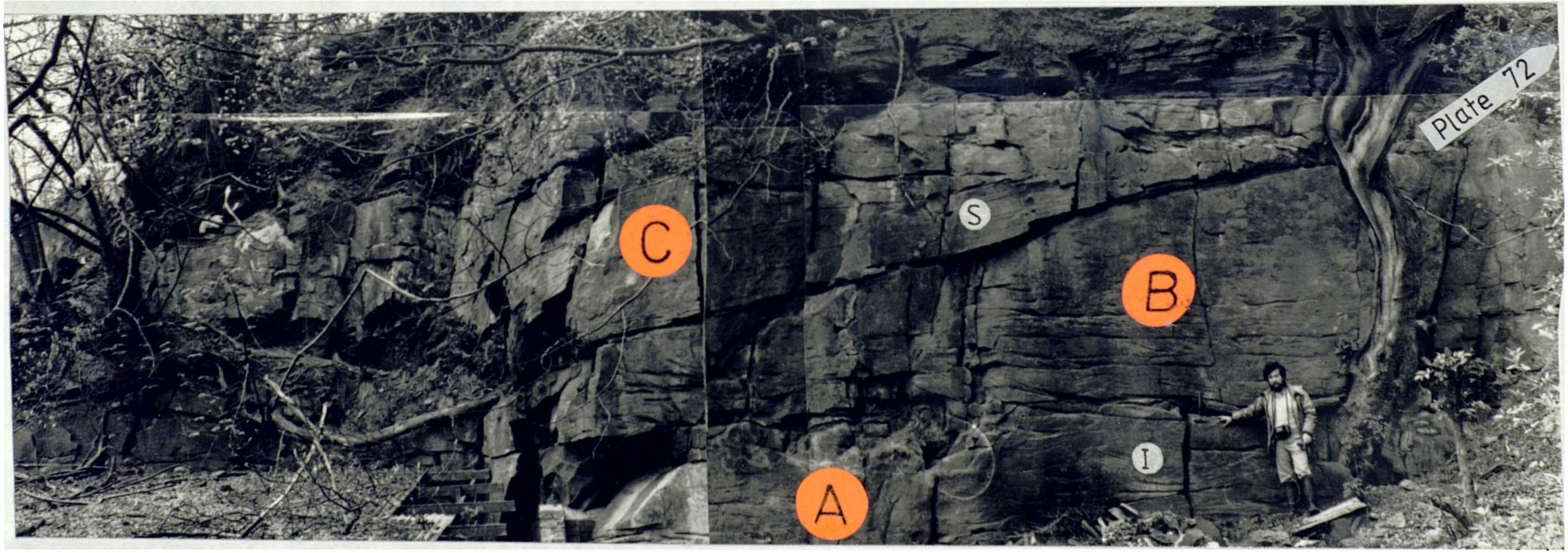


Plate 76B

Lithofacies 1), Trough Cross Bedded Sandstone, as Intraset within Lithofacies 13, Scour Based Sand body (Scale in cm). Plate is the same as I of plate 76A.


I
0
10

Plate 77

NW-SE face of quarry in Pule Hill Grit type section showing sand bodies A and C (B does not occur at this face). Note erosional surface 1; Internal erosional surfaces 2, 3 and the lithofacies 12, Large Scale Cross Bedding that occurs above the erosional surface 1 to the top end of the plate. Figure 48 is a traced sketch of this plate. Note the location and trend of plate 73 (arrow at NW end of plate 77).

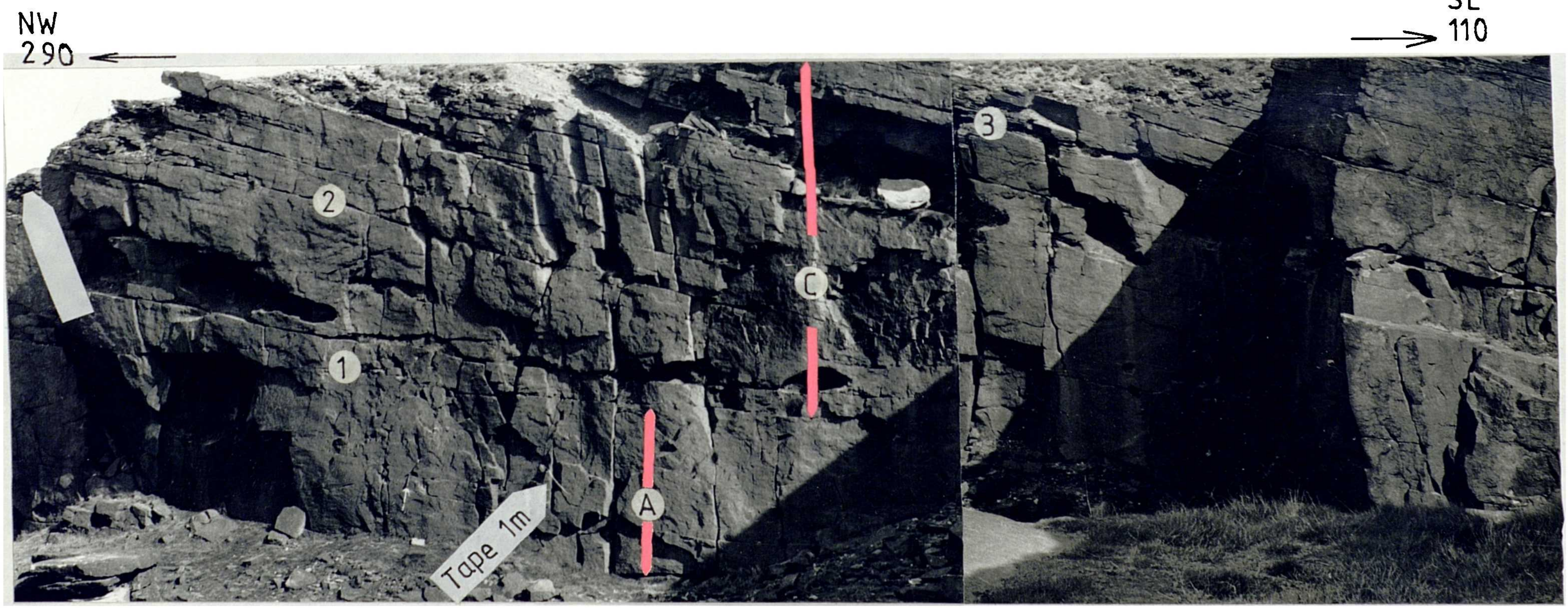

NW
290
SE
110
2
1
Tape 1m
A
C
3

Plate 78

Lithofacies 14, Horizontal bedded sandstone (in the lower parts of plate) occurring in the Scotland Flags sequence of Diggley Quarry (SE 110074, Mouth Bar). Tape (arrowed) is 1m long.

Plate 79

Scoured base of Horizontal Bedded Sandstone (Mouth Bar) in the Pule Hill Grit sequence in Readyshore Scout (SD 942198). Hammer is 33cm long.

Plate 80

Trough based unit within Horizontal Bedded Sandstone (Mouth Bar) of the Pule Hill Grit sequence in Bare Clough SE 018309, level 40m 'a'sequence Fig. 14.

Plate 81

Load at scoured base of Horizontal Bedded Sandstone (Minor Mouth Bar) of the Pule Hill Grit sequence in Ponden Clough SD 980364, level 30m, 'f' sequence Fig 17.

Plate 82A

Lithofacies 15, Lenticular sandstone bed (Crevasse Splay Sandstone) in the Pule Hill Grit sequence of Fletcher Bank Quarry SD 805165, level 26-28m, Northern Vertical Section, Fig 59. Cap (width 22cm) lies on one of the prominent Lenticular sandstone beds.

Plate 82B

Lithofacies 14, Lenticular Sandstone bed (Crevasse Splay Sandstone) in the Pule Hill Grit sequence of Fletcher Bank Quarry SD 805165. Level 41-42m, Northern Section, Fig. 59. Author's hand on the most prominent Lenticular Sandstone bed. Note other Lenticular Sandstone bed beside author's right hand side (Man is 1.8m tall).

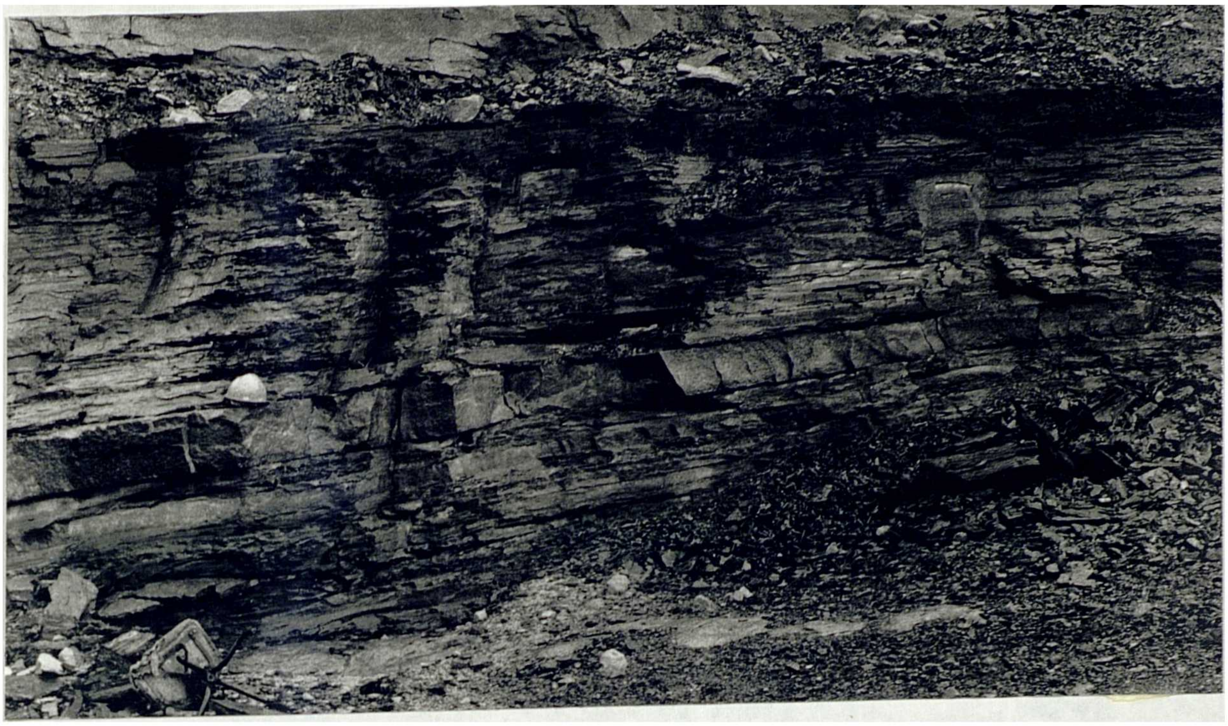


Fig 82C.

Lithofacies 15, Lenticular sandstone bed (Crevasse Splay Sandstone) in the Pule Hill Grit sequence of Fletcher Bank Quarry SD 805165, level 46-50, Northern Vertical Section, Fig. 59. Hammer (arrowed 33cm long) lies within one of the lenticular sandstone beds.

Plate 83.

Lithofacies 15, Lenticular Sandstone bed (Mouth Bar area) in the Pule Hill sequence of Readyshore Scout, SD 942198. Tape, arrowed, is 1m long and tape reel rests on the top of the Lenticular Sandstone bed.

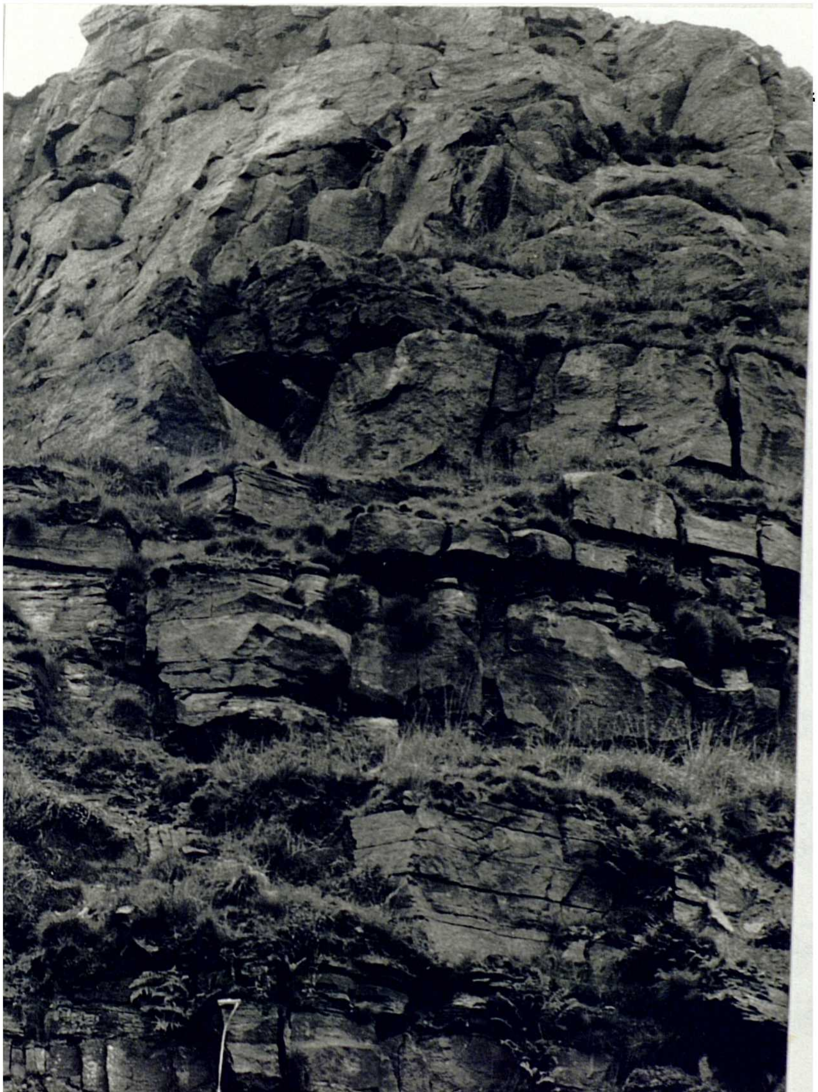


Plate 84

Lithofacies 15, Lenticular sandstone bed (Minor Mouth Bar sands within interdistributary bay) in the Pule Hill Grit sequence of Holmbridge Woodhouse Quarry (SE 129064, level 17m, Fig. 81). Note Load on base of Lithofacies 15 near hammer which is 33cm long.

Plate 85

Sinusoidal Ripples (Minor Mouth Bar) in the Hazel Greave Grit of Ramsden Clough (SE 123045, level 105m, 'd' sequence Fig. 12). Hammer (arrowed) is 33cm long.

Plate 86

Plan of Relationship between accretion dip direction and current flow direction in Pule Hill Grit type section (SE 032105). (Direction of hammer handle is towards the accretional dip direction. Pointed end of hammer is towards the current flow direction).

Plate 87A

Pebbles (lag deposits, most prominent below horizontal chalk line) concentrate at the base of lithofacies 17, Massive Sandstone (Distributary Channel) in the Pule Hill sequence of Ponden Clough (SD 980364, level 55m, 'f' sequence, Fig 17). Two pence piece, on chalk mark, is 27mm in diameter. Arrow near hammer points at other pebble concentration which is indistinct in the Plate.

Plate 87B

The same base of lithofacies 17, Massive Sandstone in Pule Hill sequence of Ponden Clough as in Plate 87A but showing plant remains (lag deposits). See plant below chalk mark and slightly above hammer head (Hammer 33cm long).

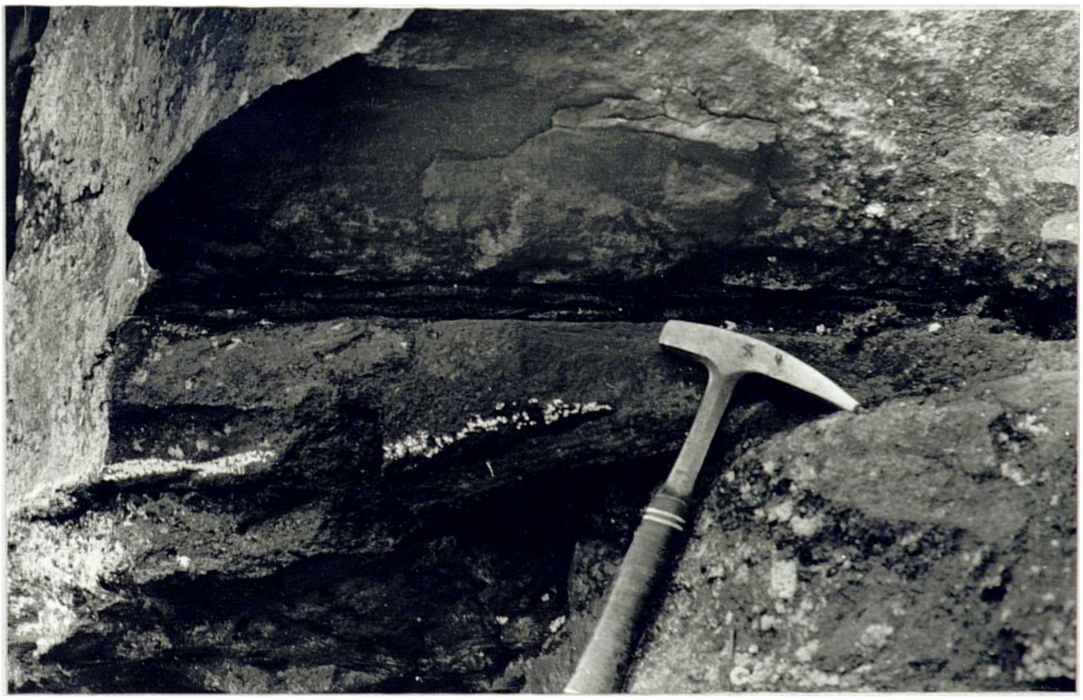


Plate 87C

The same base of lithofacies 17, Massive Sandstone in Pule Hill sequence of Ponden Clough as in Plates 87A and B but showing sandstone blocks, C1; pebbles, C2; and plants C3 (Lag deposits). Hammer head for scale.

Plate 88

Erosive base of lithofacies 17, Massive Sandstone (Channelized Mouth Bar Area) in Pule Hill Grit sequence of Heyden Road Exposure SE 097035, level 10.5m, Fig. 56. Hammer 33cm long lies on Lithofacies 8, Trough Cross Laminated Sandstone.


C3
C1
C2
C1
C3

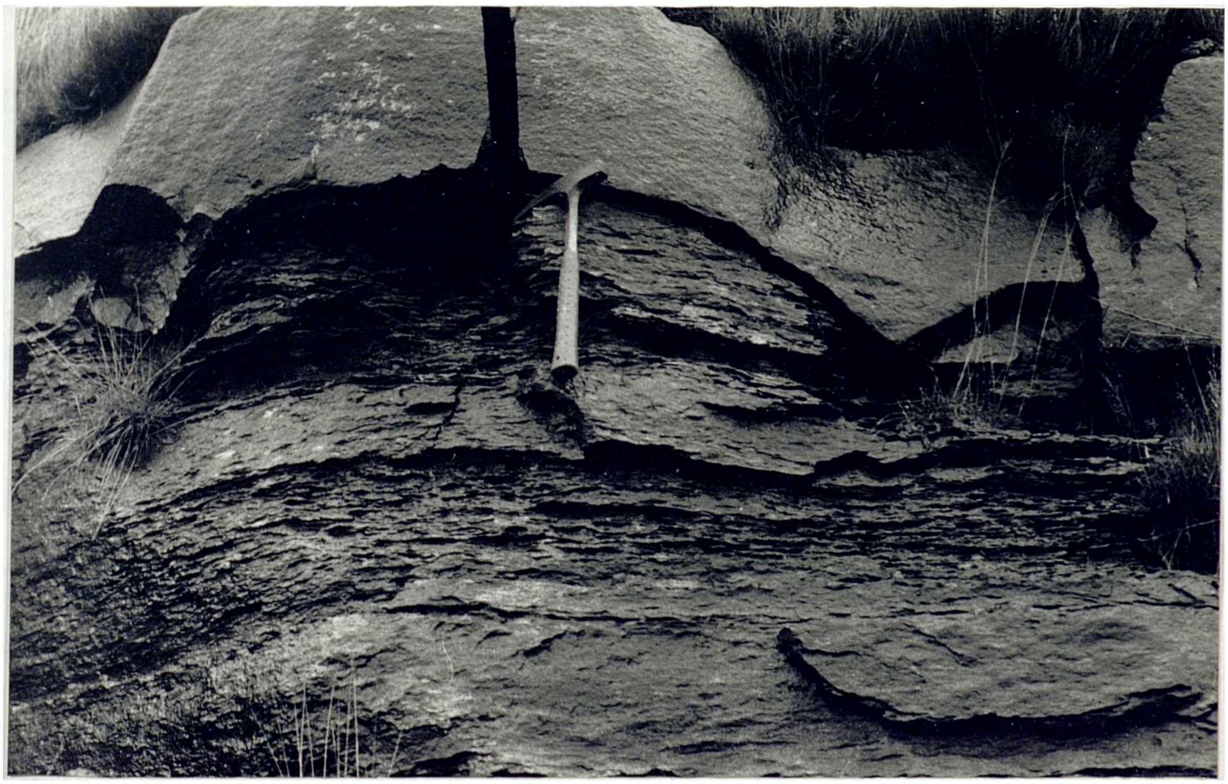


Plate 89

Lithofacies 18, Pinch and Swell Sandstone (Channel Units) in Hazel Greave type section (SD 915240, near Todmorden). Hammer 33cm long lies on a sand unit which pinches on both sides. Tape 1m long. Tape reel lies on a sand unit which pinches on both sides.

Plate 90

Flutes at base of lithofacies 19, Turbidite-like Sandstone (Turbidites) in Pule Hill Mudstone of Gorpley Clough (SD 915235, level 23.8m, Fig. 54. Arrows point to gentle end of flute. Ten pence piece is 29mm in diameter.

Plate 91

Longitudinal furrows and ridges at base of turbidite-like sandstone (Turbidites)in Pule Hill Mudstone (Prodelta) of Gorpley Clough (SD 915235, level 15m, Fig 54).

Plate 92A

Prod and Bounce Marks at base of turbidite-like Sandstone (Turbidites) in Pule Hill Mudstone of Gorpley Clough (SD 915235,level 15m, Fig. 54).


MM
1
2
3
4
5


MM
1
2
3
4
5

Plate 92B.

Prod and Bounce Marks at base of turbidite-like Sandstone (Turbidites) in Pule Hill Mudstone of Gorpley Clough (SD 915235, level 15m, Fig. 54).

Plate 93A.

Load structure arrowed at base of turbidite-like sandstone (Turbidite) in Pule Hill Mudstone (Prodelta) of Gorpley Clough (SD 915235, level 14.7m, Fig. 54). Ten pence piece is 29mm in diameter. Hammer is 40cm long.


16

Plate 93B

Sole Marks at base of turbidite-like sandstone (Turbidite) in Pule Hill Mudstone (Prodelta) of Gorpley Clough (SD 915235, level 15m, Fig. 54).

Plate 94

Vertically Oriented Rootlets in Lithofacies 20, Seat-earth (Swamp) capping the Pule Hill Grit sequence in Warland Wood Quarries (SD 948202, level 29m, Fig. 24). Hammer is 40cm long.


MM
1
2
3
4
5

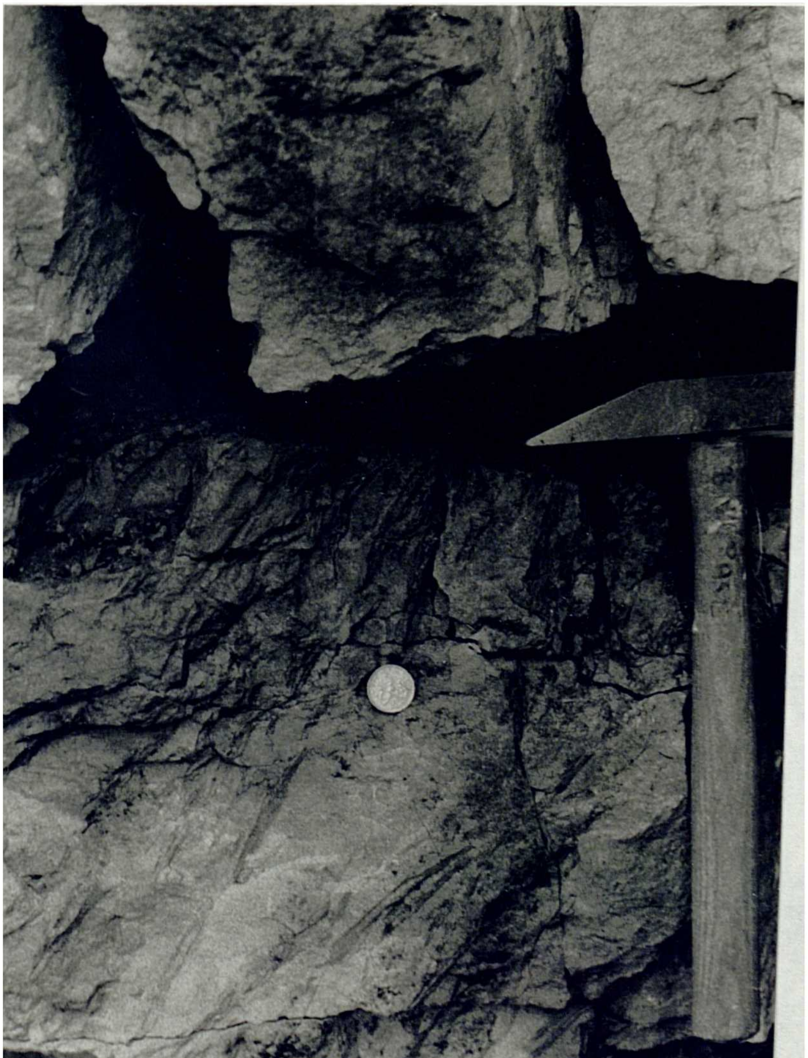


Plate 95

Horizontally in-situ Stigmaria in lithofacies 20, Seat-earth (Swamp) capping the Pule Hill Grit sequence in Warland Wood Quarries (SD 948202), level 29m, Fig. 24). Hammer is 40cm long. Note that each pair of horizontal chalk marks delineate the outside boundaries of each of the two prominent in-situ Stigmaria.

Plate 96

Stigmaria root (right of marker) and rootlets in Lithofacies 20, Seatearth (Swamp) capping Channel 3 sequence (Pule Hill Grit) in Fletcher Bank Quarry (SD 805165, level 25.5m, Northern Vertical Section, Fig. 59). Diameter of root is 8cm (Marker is 11cm long).

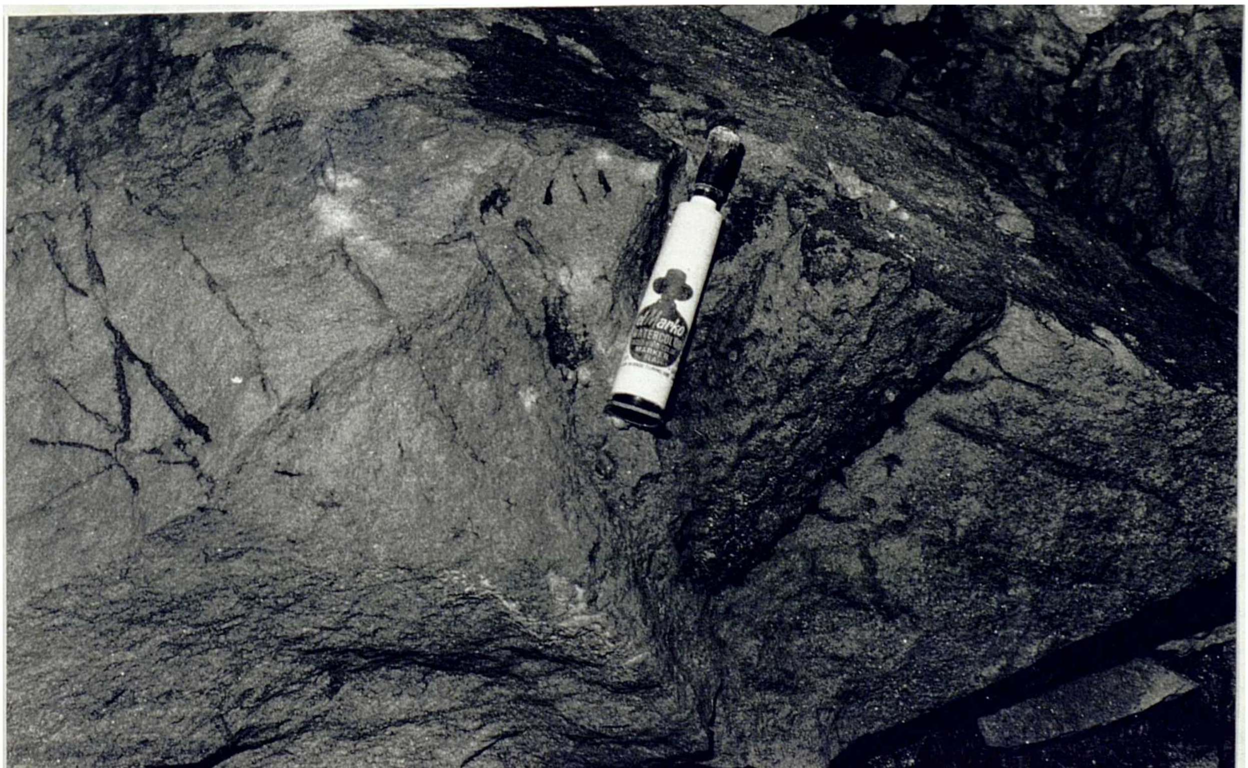
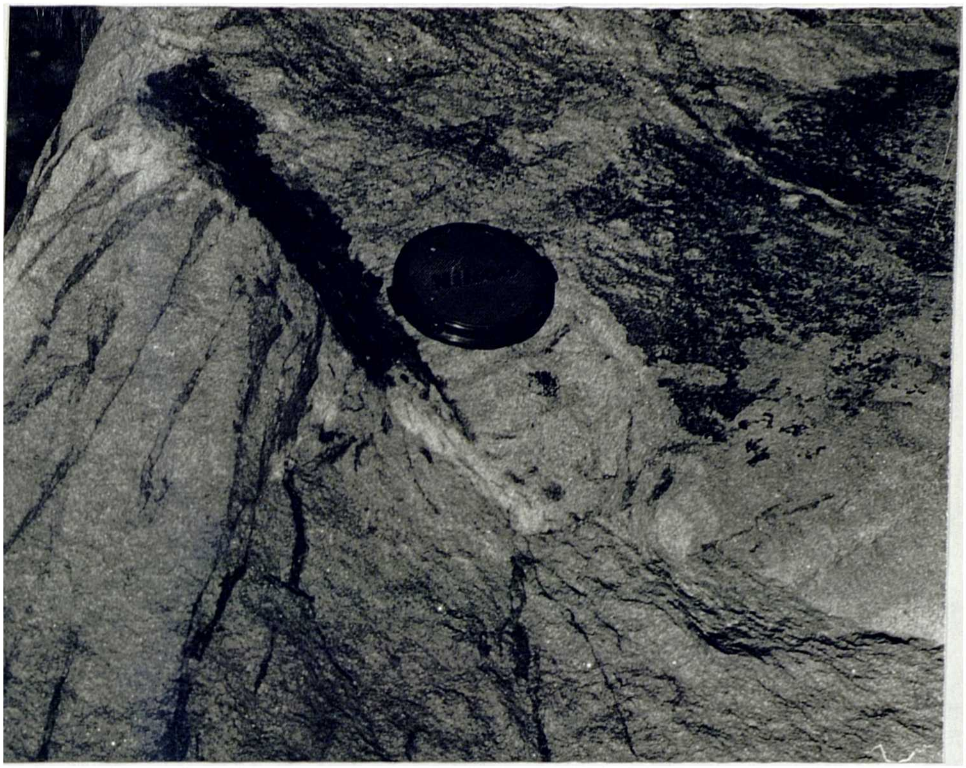


Plate 97

Horizontally orientated Stigmaria and its attached vertical rootlets in lithofacies 20, Seatearth (Swamp) capping Channel 3 sequence (Pule Hill Grit) in Fletcher Bank Quarry (SD 805165, level 25.5m, Northern vertical Section, Fig 59. Diameter of Nicon cap is 5.5cm.

Plate 98

Escape shaft of Pelecypodichnus (Vertical chalk on shaft) and inclined rootlets (arrowed) in lithofacies 10, Trough Cross Bedded Sandstone (Crevasse Channel) of the Pule Hill Grit in Cowloughton Clough (SD 965413, level 58m 'e' sequence Fig. 17). Marker is 11cm long.



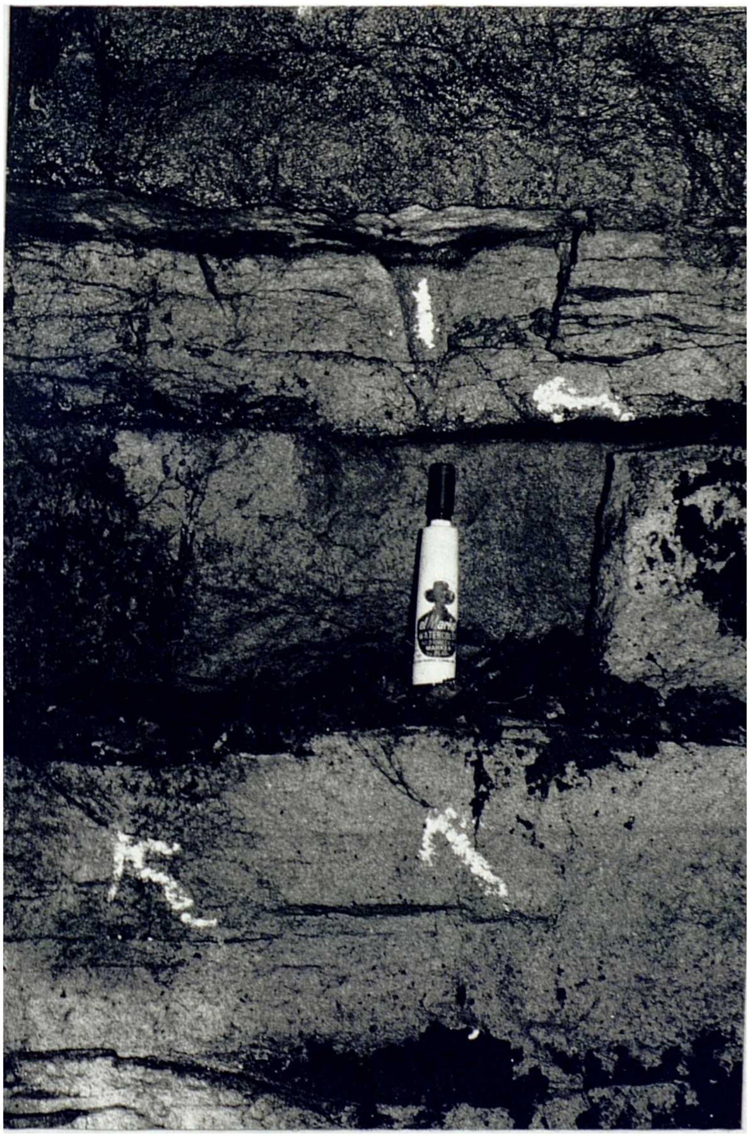


Plate 99

Vegetable rich coal, the lower coal, Type B Coal (Swamp) capping the thickest Pule Hill Grit distributary channel in Cowloughton Clough (SD 965414, level 54m, 'e' sequence Fig. 17). A yellowish to brownish grey seatearth underlies Coal down to the base of this plate. Hammer is 33cm.

Plate 100

Goniatite in nodule within the Hazel Greave Mudstone (Marine Prodelta) in Sunny Bank Cutting (SD 780206, level 7m 'b' sequence Fig. 16). Five pence piece is 24mm in diameter. (Plate 100 is the same as the extreme right nodule in Plate 11).


Coal
Coal

Plate 101A

Base (arrowed) of Fletcher Bank Channel 1 in Pule Hill Grit sequence of Fletcher Bank Quarry. Note truncation of Bay fill sandstone unit. Tape reel rests on the lower part of this Bay fill sandstone unit. Lower part of tape (1m long) is on mudstone (SD 805165, level 1.5-7m, Central Vertical section Fig. 59A).

Plate 101B

Base (arrowed) of Fletcher Bank Channel 1 in Pule Hill Grit sequence of Fletcher Bank Quarry. Note undulatory scour base of channel. Tape 1m exposed (SD 805165, See 5 in Fig. 59B for location of Plate 101B.


Tape 1m


Tape 1m

Plate 102

Central and Southern parts of Fletcher Bank Quarry in Pule Hill Grit, showing Channels 1 to 4. Note that Fig. 60 is a traced sketch of this Plate and that the central and southern parts of this quarry is the same as locations 2 and 3 of Figs. 59A and B. Note locations of Plate 101A and 103 in this Plate. (SD 805165).

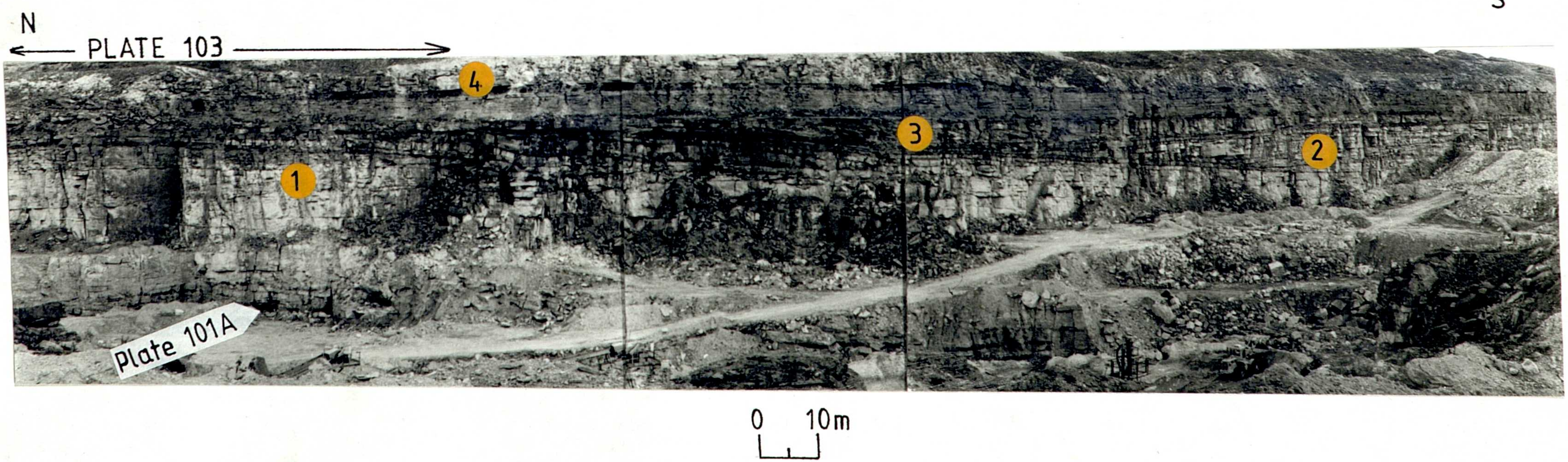
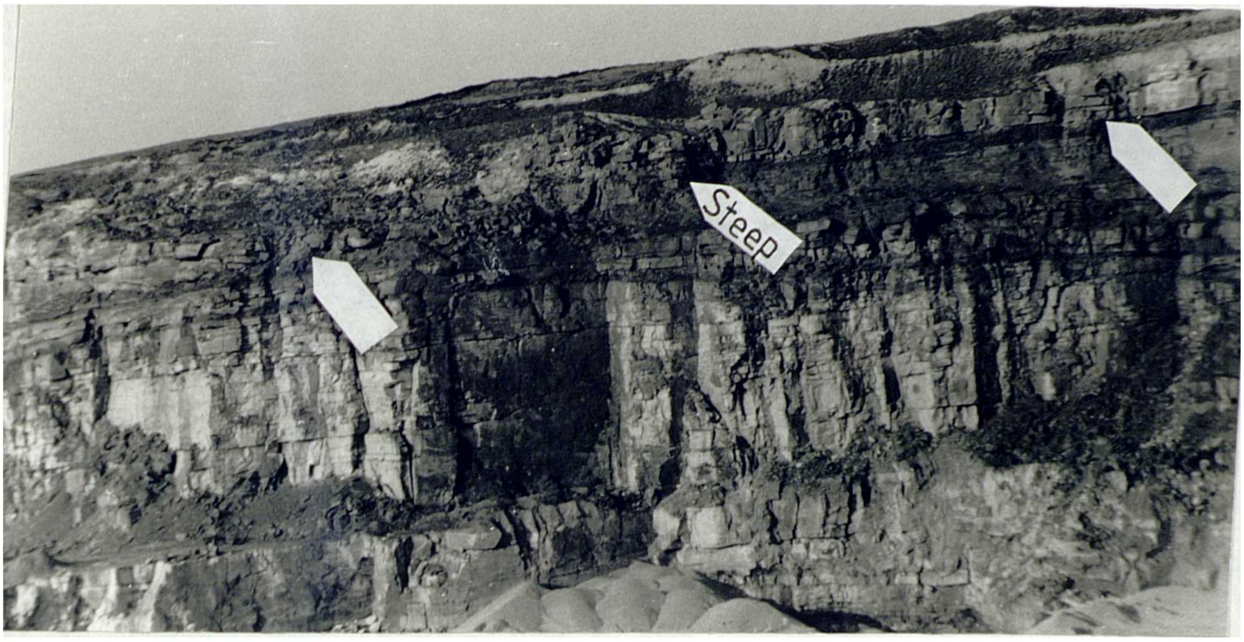

N
PLATE 103
S
4
3
1
2
Plate 101A
0 10m

Plate 102

Erosional base (arrowed) of Channel 4 in Pule Hill Grit of Fletcher Bank Quarry. Note the sharp, horizontal and prominently flat base (right arrow; see also Plate 17 for its close-up photograph and Plate 102 for lateral extent). Note also steep (3.7m) scour of this base (central arrow) into finer grained bay sediments before it maintains a low level (left arrow) northwards. See Plate 102 for the location of Plate 103 relative to the overall quarry face.

Plate 104

Groove at base of Channel 2 in the Pule Hill Grit of Fletcher Bank Quarry (SD 805165, level 14m, Southern Vertical section Fig. 59A).


Steep

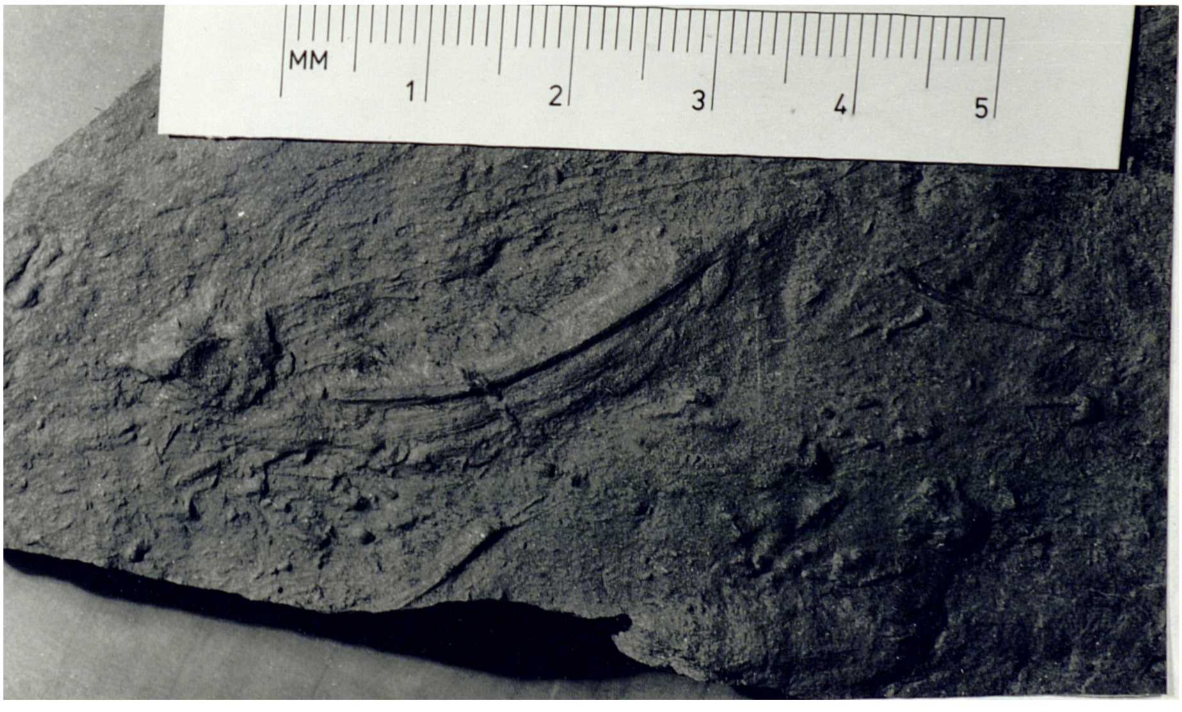
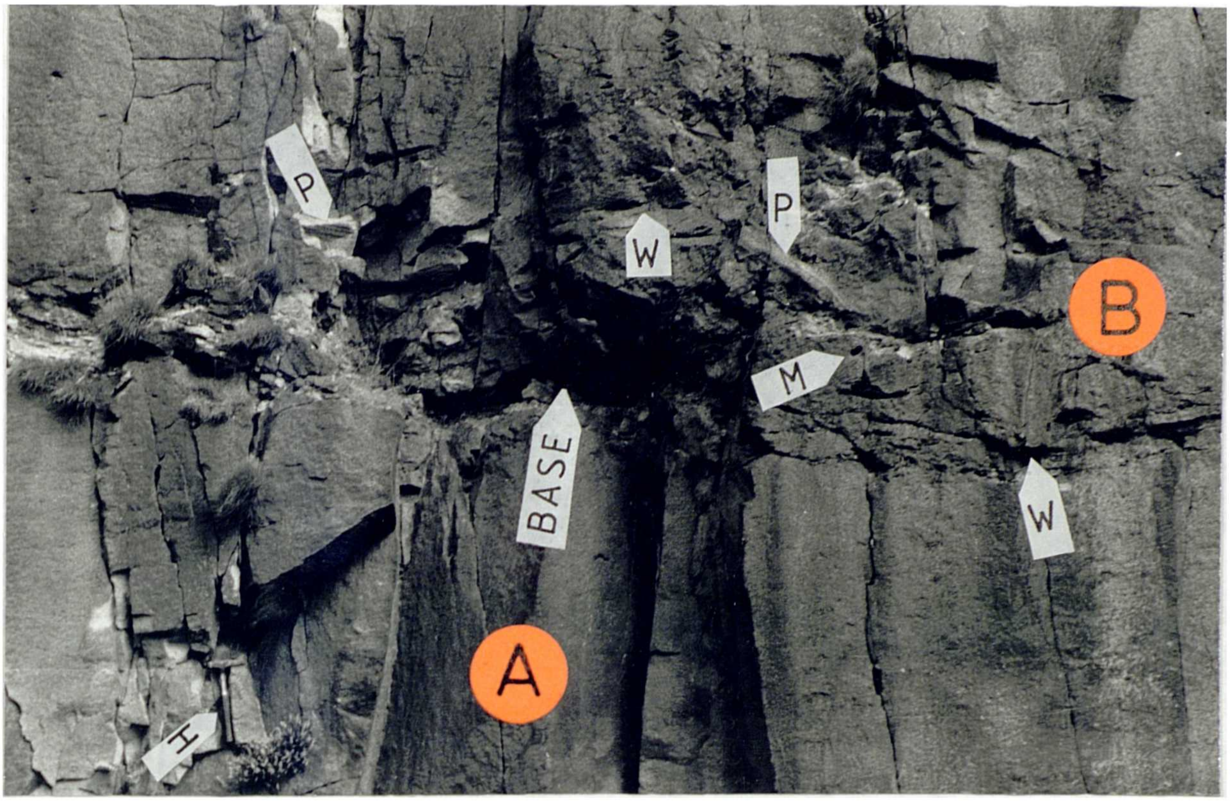

MM
1
2
3
4
5

Plate 105

Dumped plant fragments (P); Wood (W) and Mud Clasts (M); interpreted as lag deposits, at the base of sheet sandstone (A), regarded as a distributary channel. /‾Hazel Greave Grit in Bracken End Quarry (SE 194433) near Guiseley_7. Hammer (H) which is 33cm long is in sheet sandstone B.

Plate 106

Dumped wood (arrowed) at base of sheet sandstone A, (distributary channel) in Hazel Greave Grit of Carlton Lane Quarry (SE 199431) near Guiseley. Hammer 33cm long.


P
P
W
B
M
BASE
W
A
H

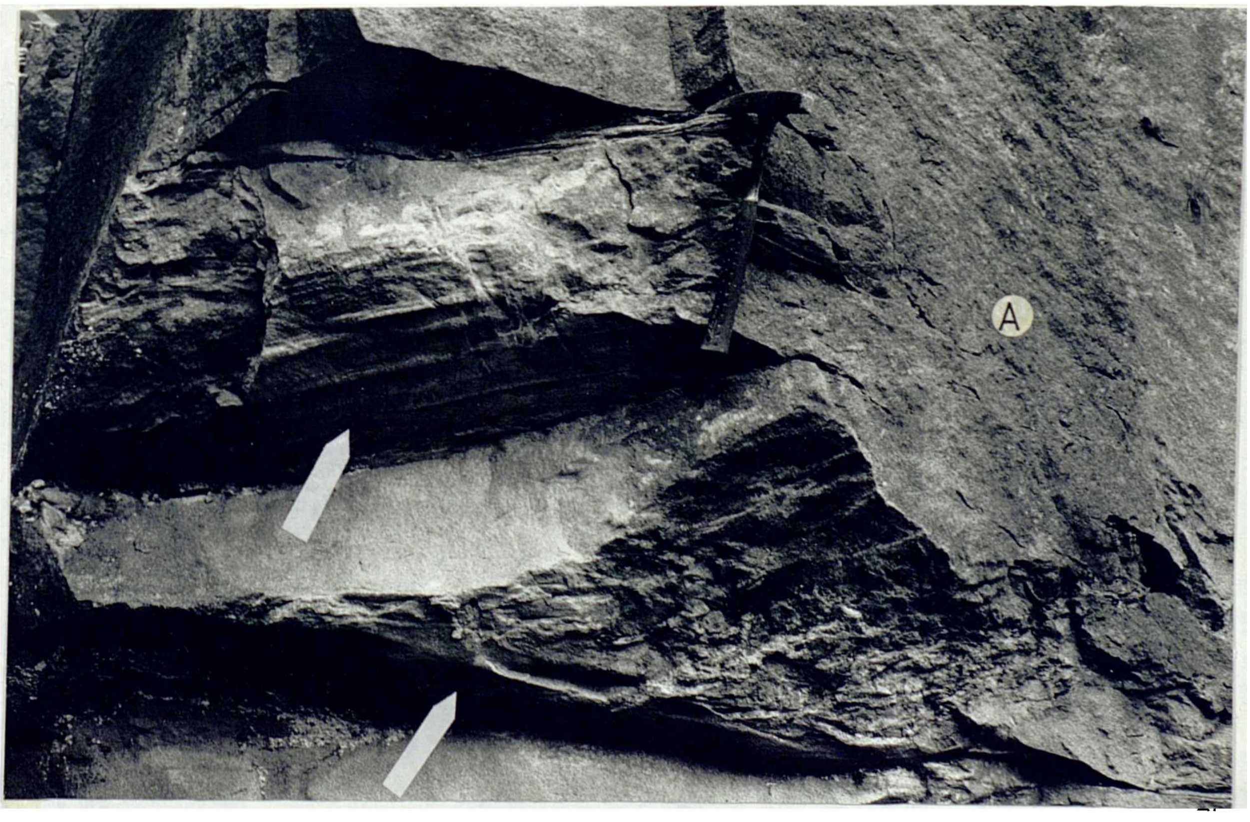

A

Plate 107

Abundant Mudstone clasts at base of the sheet Channel 2 in Pule Hill Grit sequence of Readyshore Scout (SD 942198). Hammer handle rests on the zone of abundant mudstone clasts in Channel 2. See Channel 3 on top of Channel 2. Hammer 33cm long.

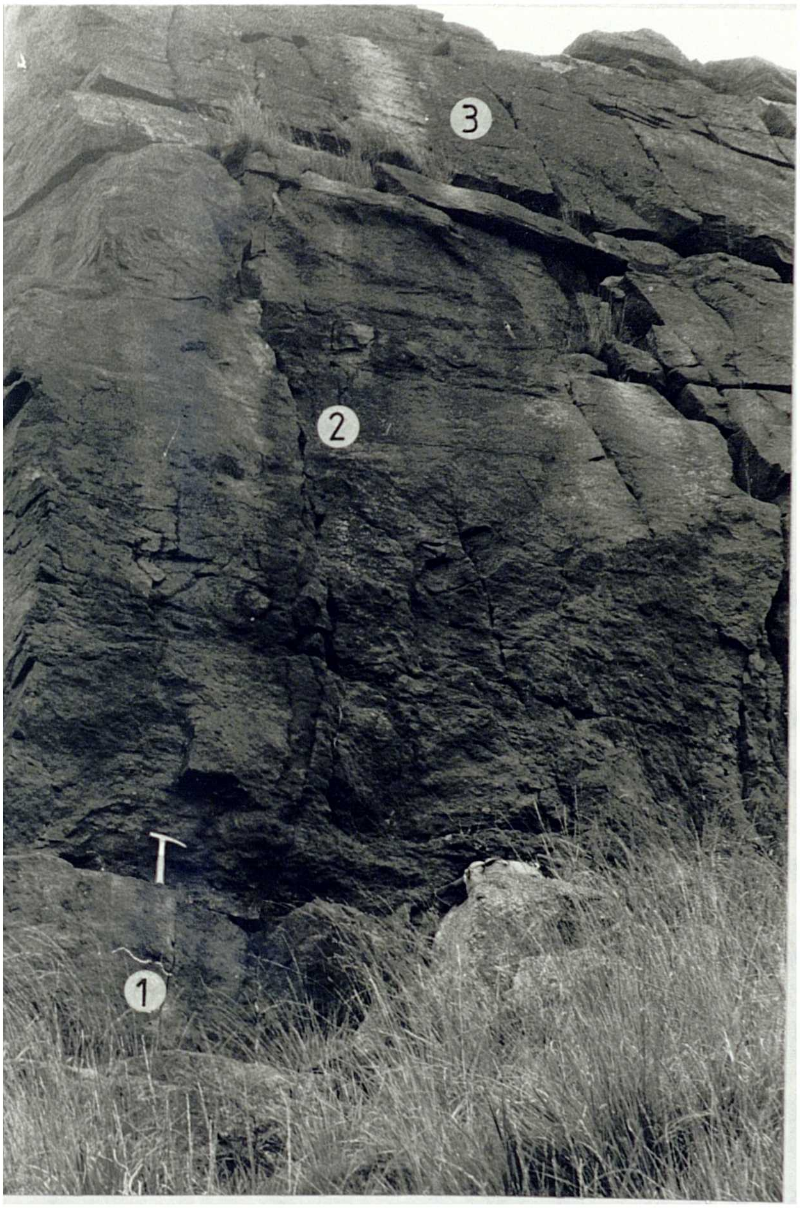

3
2
1

Plate 108

Wicking Crag NW-SE Face showing Hazel Greave Interval, comprising of *R. bilingue* late band b(L), Hazel Greave Mudstone (HM, the upthrown (UHG) and downthrown (DHG) blocks of Hazel Greave Grit. Line Connecting the Y's marks the concave trace of fault (Hammer 33cm).

Note the location of Plate 64 (see NW end) in Plate 108.

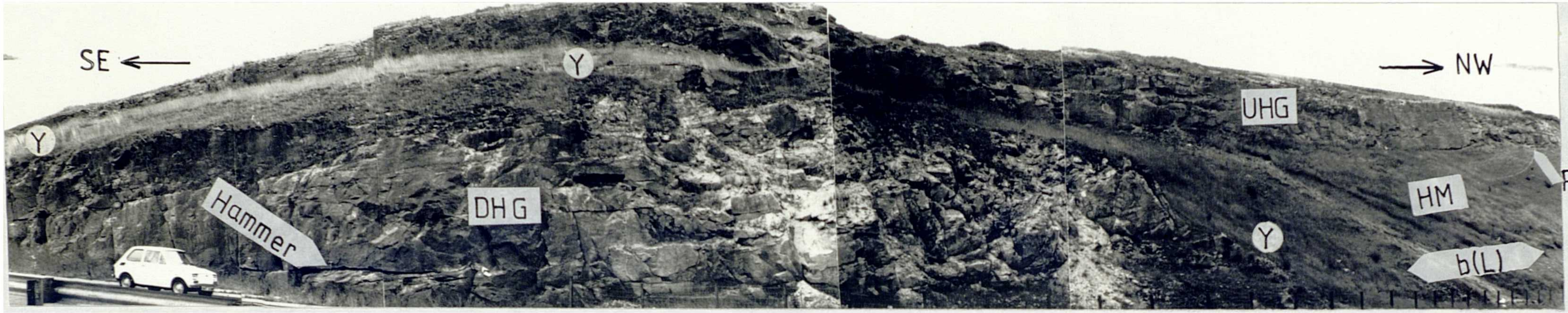


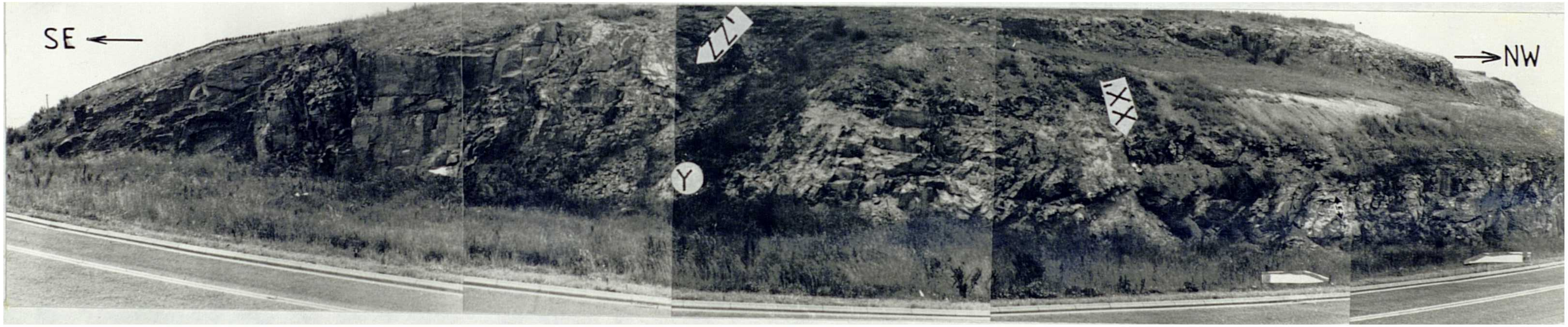
Plate 64

Plate 109

NW-SE face of Hazel Greave Grit in Wicking Crag Quarry showing faults YY', XX' ZZ' and the slump zone which extends from Y to the right basal arrow (near road). See Figure 74, which is a sketched trace of this plate, for further details. The 2 basal arrows (near road) mark the lateral extent of Plate 110.

Plate 110

Close-up photograph of NW parts of Plate 109 (see two basal arrows at right side of Plate 109 for limits of Plate 110) showing slump at the downthrown block (see Plate 108) of the Hazel Greave Grit (Distributary Channel) in Wicking Crag Quarry. The details of faults, undulating laminae (UL, balls (b) encircled by laminae and parallel stratified laminae (p) can be seen in Fig. 75 which is a traced sketch of Plate 110. Tape is 1m long. Note the position of Plate 134 in Plate 110.



0 2m

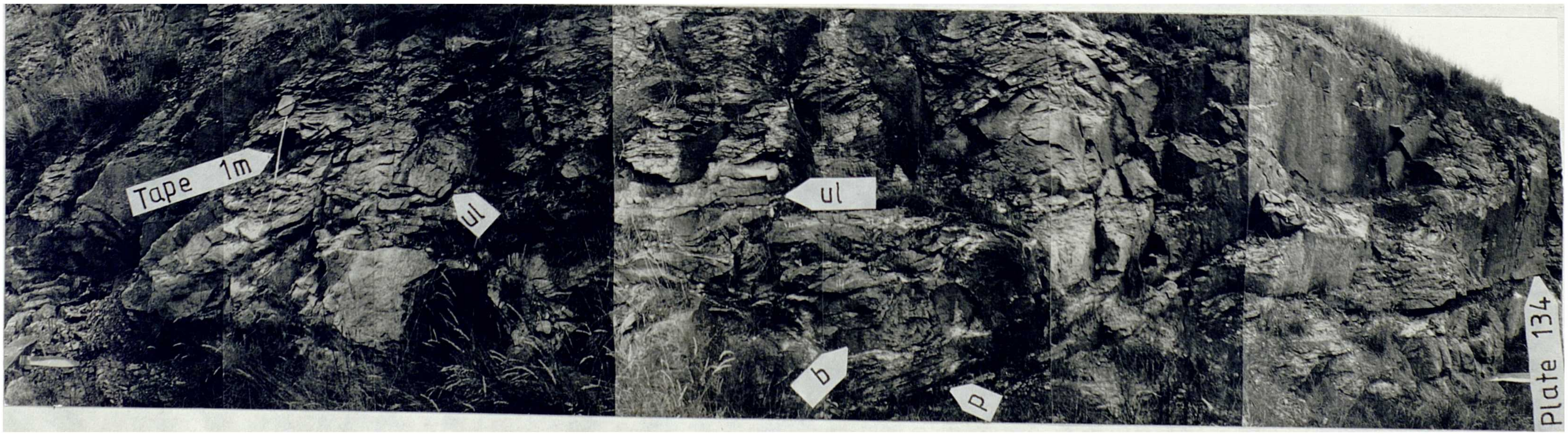


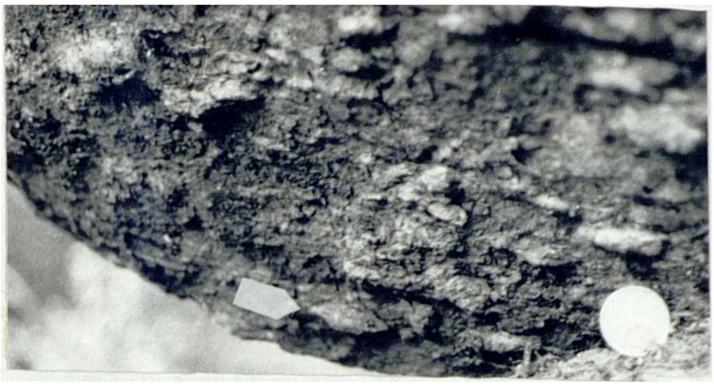
Plate 134

Plate 111

Abundant Pelecypodichnus (one of which is arrowed) at the Sandstone base (Levee) of the Pule Hill Grit in Harper Clough Quarry (SD 717318, level 12m, Fig. 78B). Ten pence piece is 29mm in diameter.

Plate 112

Stigmaria Root, and rootlets in the Pule Hill Grit of Woodhouse Quarry(SE 062397 , level 11m, Fig. 82). Marker is 11cm long.



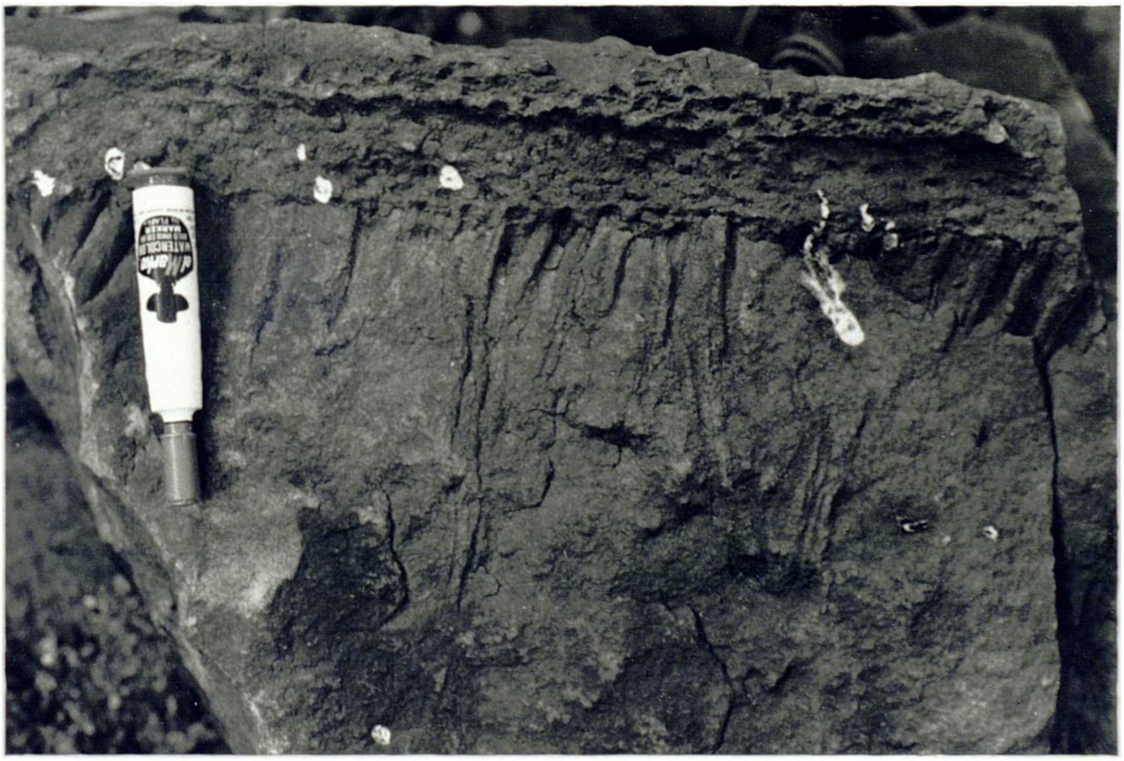


Plate 113.

Channel (CH) in Mouth Bar Area (Pule Hill Grit), Ramsden Clough. (SE 121038, level 82-86m, 'd' sequence, Fig. 12). Note undulatory sharp base (arrowed) into lithofacies 6, Siltstone. Tape 1m exposed (See chalk marked arrows at channel base for tape location).


CH

Plate 114

Arenicolites in lithofacies 9, Parallel Laminated Sandstone of Crevasse Splay origin in Pule Hill Grit sequence of Fletcher Bank Quarry (SD 801167, 50-51m level, Fig. 59, Northern Vertical section). Pencil (15cm long) points at bed in which Arenicolites is best developed.

Plate 115

Arenicolites with funnel (Y) developed in the same quarry face and level as in Plate 114. Note also one limb of Arenicolites (V) overlapping the other limb (O). Note simple U-shaped Arenicolites arrowed.

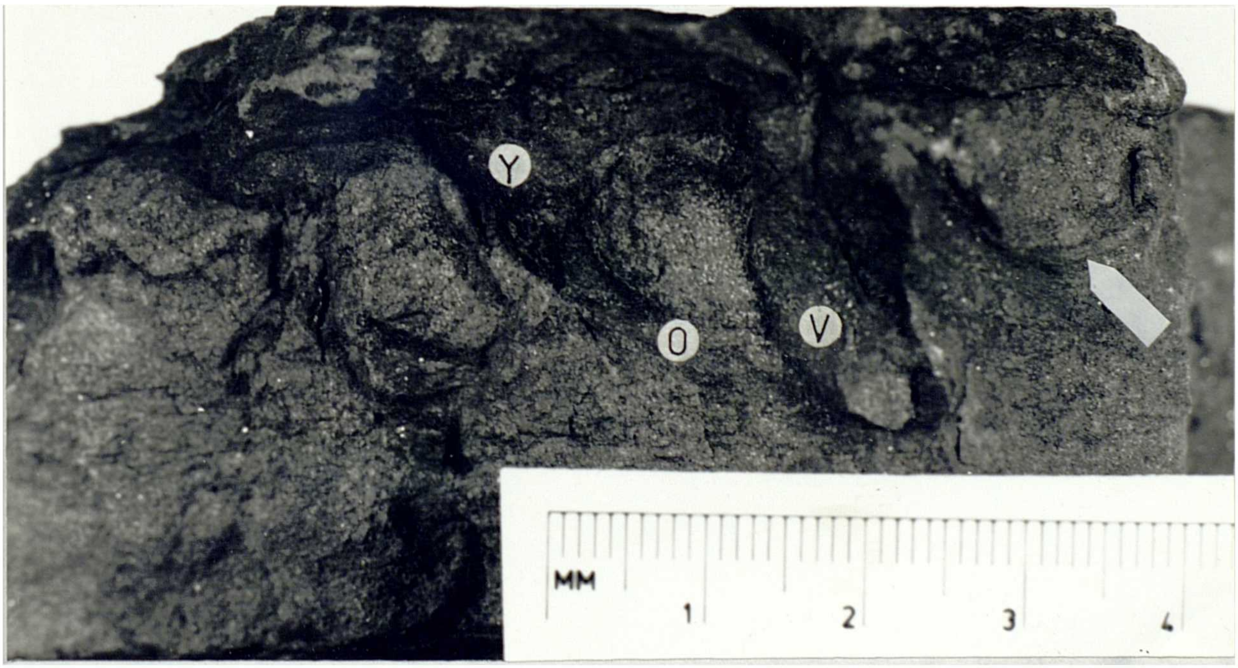

Y
O
V
MM
1
2
3
4

Plate 116

Arenicolites whose tops are truncated. Note erosional surface (arrowed) whose irregular surface follows the truncated tops of _Arenicolites_. (Plate 116 is from the same quarry and level as in Plate 114).

Plate 117A

Arenicolites (arrowed) whose one limb is wider than the other limb (Plate 117A is from the same quarry and level as in Plate 114).

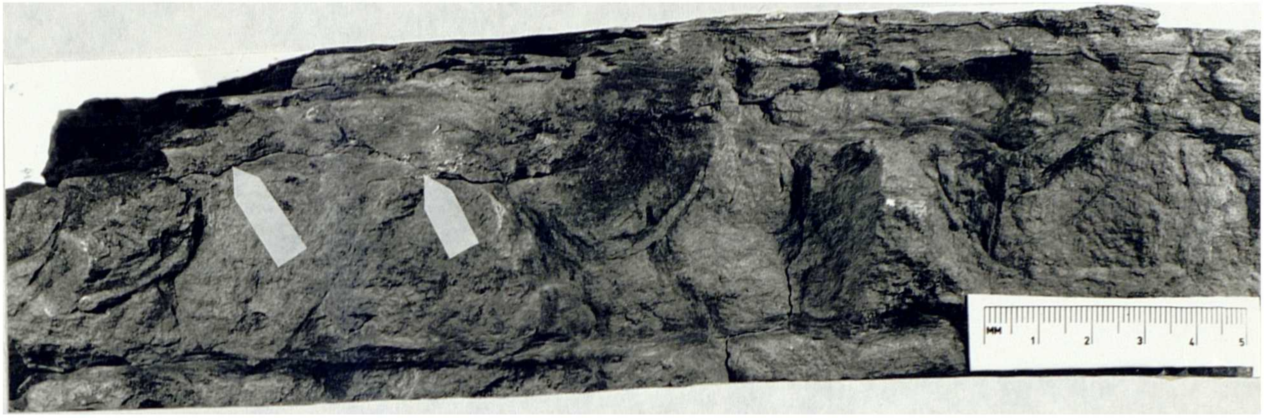


Plate 117B

<u>Arenicolites</u> with lateral spreite. Sand cast arrowed retained at outer end of wider limb. (Plate 117B is from the same quarry and level as in Plate 114).

Plate 118

<u>Arthrophycus</u> as convex hyporelief at the base of lithofacies 15, Lenticular Sandstone Beds (Crevasse Splay origin) of the Pule Hill Grit sequence exposed in the northern part of Fletcher Bank Quarry (26-28m level, Fig. 59; Plate 82A). (See Fig. 95 which is a traced sketch of this plate showing the branching angles and cross cutting relationships of the tubes). Tape is 5cm long.

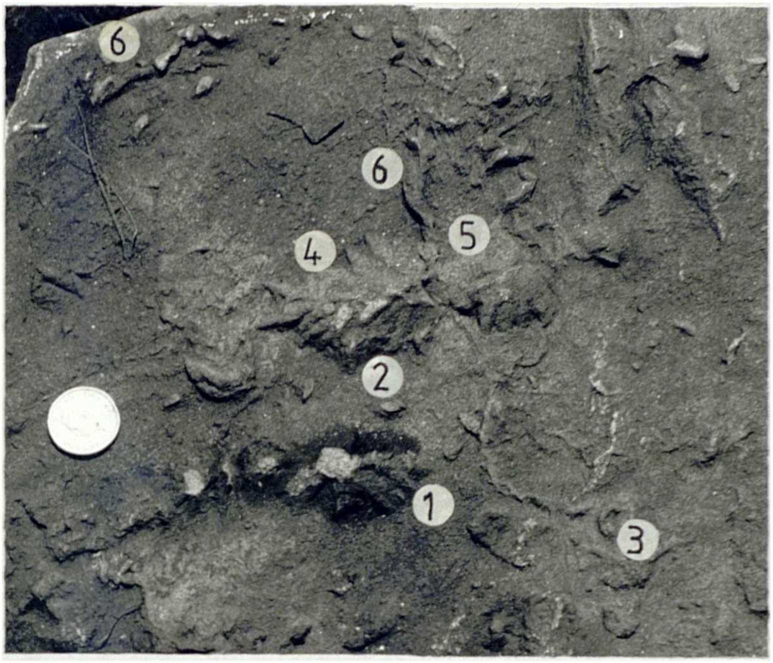

MM
1
2
3

Plate 119

Gyrophyllites (1); ?_Phycodes palmatum (4,5);_ _Kouphichnium (3)_; _Cochlichnus (6)_, and _Pelecypodichnus_ (2), preserved at the base of Lithofacies 10. Trough Cross Bedded Sandstone (Mouth Bar Area), in Pule Hill Grit exposed in Park Wood Quarry 3 (SE 067406) near Keighley. (Ten pence piece is 29mm in diameter).

Plate 120

Gyrophyllites (arrowed) at the base of Lithofacies 10, Trough Cross Bedded Sandstone (Mouth Bar Area), in Pule Hill Grit exposed in Park Wood Quarry 3. (Ten pence piece is 29mm in diameter).


6
6
5
4
2
1
3

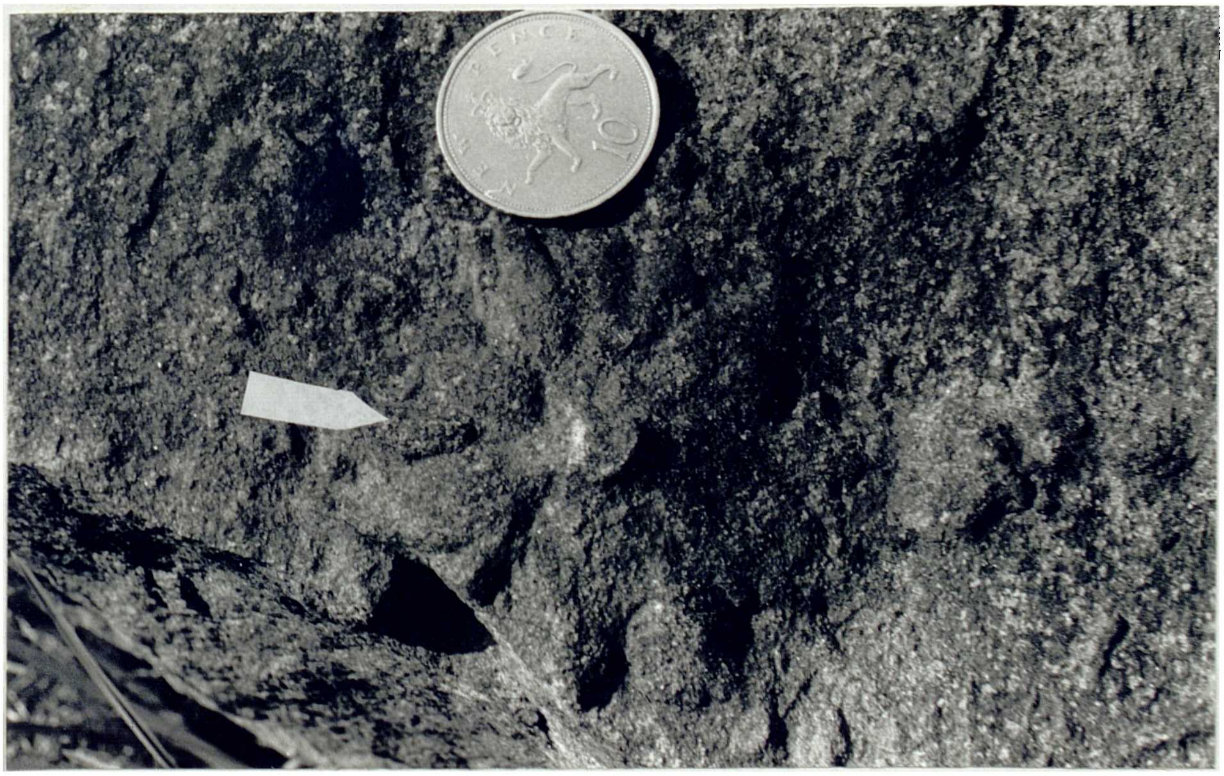
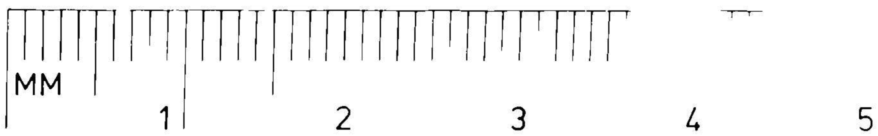

NEW PENCE
10

Plate 121A

Kouphichnium _rossendalensis_ (solitary form) preserved at the base of Lithofacies 10, Trough Cross Bedded Sandstone (Mouth Bar Area), in Pule Hill Grit exposed in Park Wood Quarry 3.

Plate 121B

Kouphichnium _rossendalensis_ (group), preserved at the base of Lithofacies 10, Trough Cross Bedded Sandstone (Mouth Bar Area), in Pule Hill Grit exposed in Park Wood Quarry 2. (Pencil is 6cm long).


MM
1
2
3
4
5

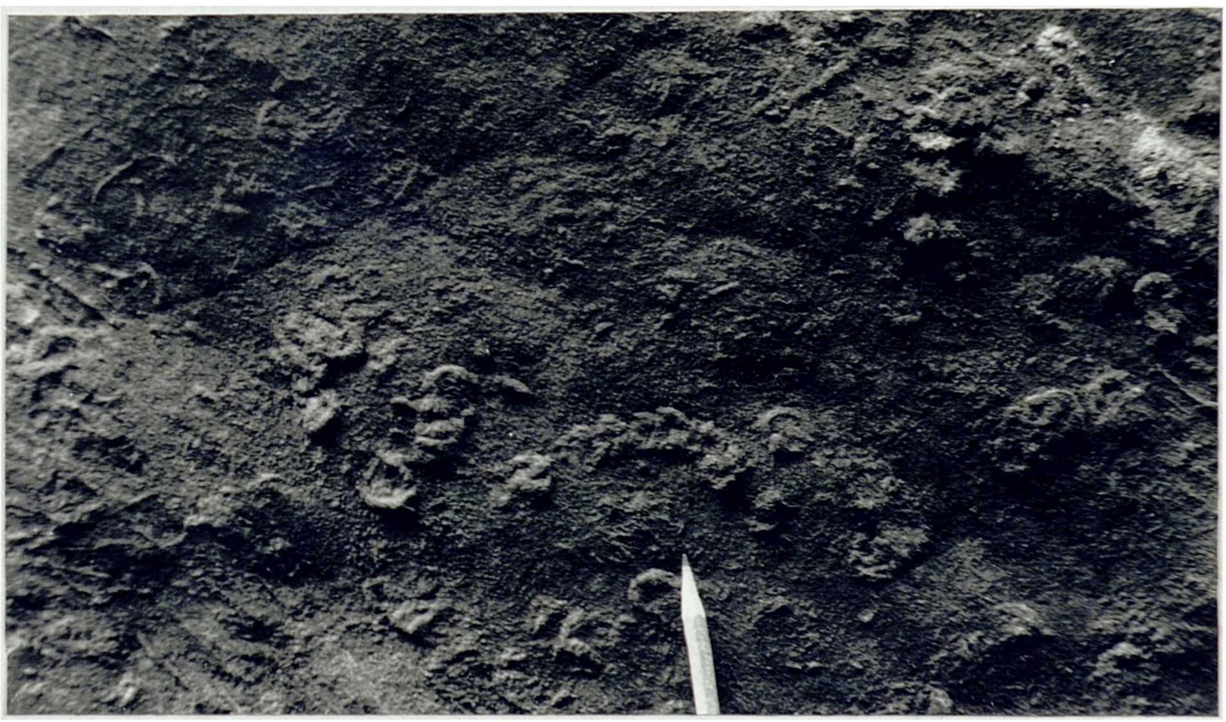


Plate 122

Palaeophycus preserved as convex hyporelief beneath Lithofacies 10, Trough Cross Bedded Sandstone of the Distributary Channel No. 2. in Fletcher Bank Quarry. (Compas is 10cm long). See Figure 98 which is a traced sketch of this plate illustrating *Palaeophycus* dimensions.

Plate 123

Palaeophycus preserved as convex hyporelief beneath Lithofacies 10, Trough Cross Bedded Sandstone of a Mouth Bar (6.3m level of Figure 80, Hazel Greave Grit) in Scout End Quarry (SD 944190). Arrow shows point of branching which is usually characteristic of *Palaeophycus*.

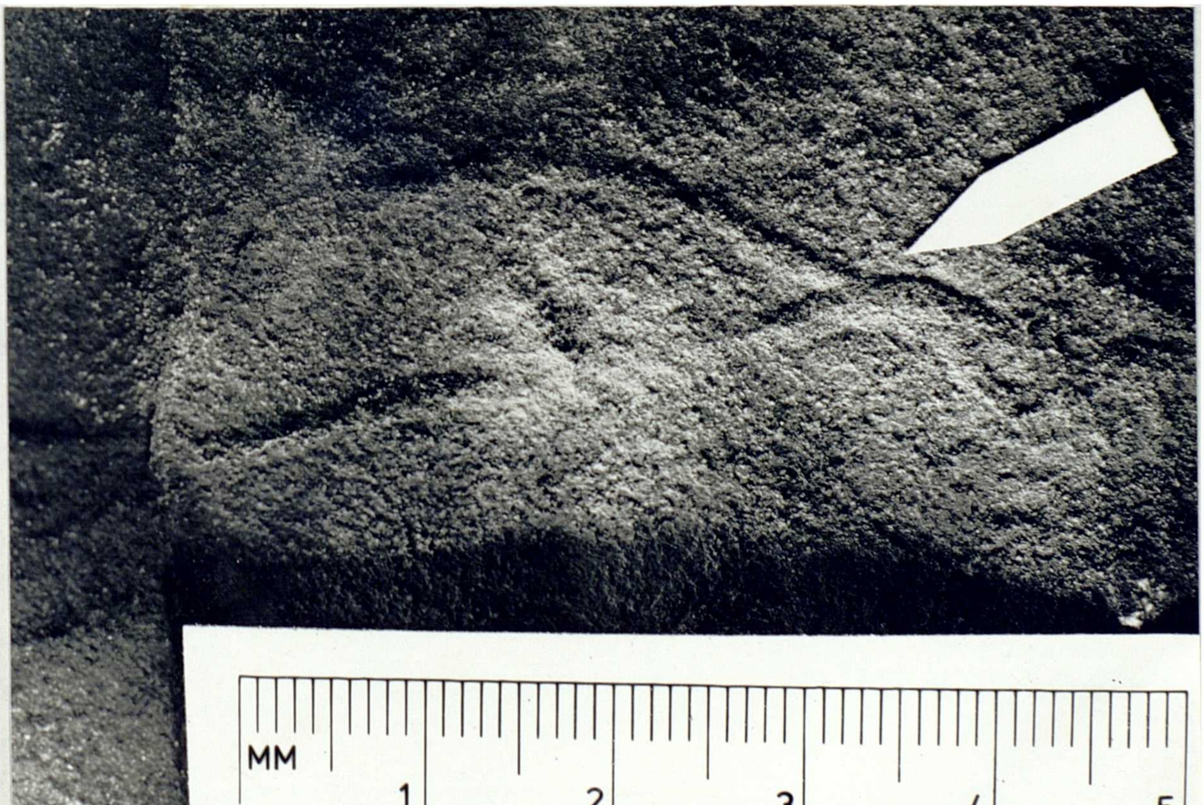

MM
1
2
3
4
5

Plate 124A

Cubichnia (resting trace) of <u>Pelecypodichnus</u> convex hyporelief on the sole of a lithofacies 10, Trough Cross Bedded Sandstone (Cravasse Channel) in Scotland Flags Quarry (SE 033268, 15.2m level, Central Vertical Section Fig. 55). Two pence piece is 27mm in diameter.

Plate 124B

Cubichnia of <u>Pelecypodichnus</u>. Concave epirelief on the top of a lithofacies 10, Trough Cross Bedded Sandstone (Crevasse Channel) in Scotland Flags Quarry (SE 033268, 15.7m level, Central Vertical Section, Fig. 55). Two pence piece is 27mm in diameter.

Plate 124C

Domichnia, dwelling structures (arrowed) of <u>Pelecypodichnus</u> in Lithofacies 8, Trough Cross Bedded Laminated Sandstone (Levee) in Scotland Flags Sequence at Castle Carr Quarry (SE 028301). Note curvature of shaft.

<u>Plate 125</u>

<u>Pelecypodichnus</u> in Lithofacies 14, Horizontal Bedded Sandstone (Bay fill deposit) in the Pule Hill Sequence of Fletcher Bank Quarry. Note the direct connection of hypichnial bump to the epichnial depression of the endichnial shafts (arrowed). Chalk marks are on large hypichnial bumps which are commonly 3cm in length (3.5m level, Central Vertical Section, Fig. 59).

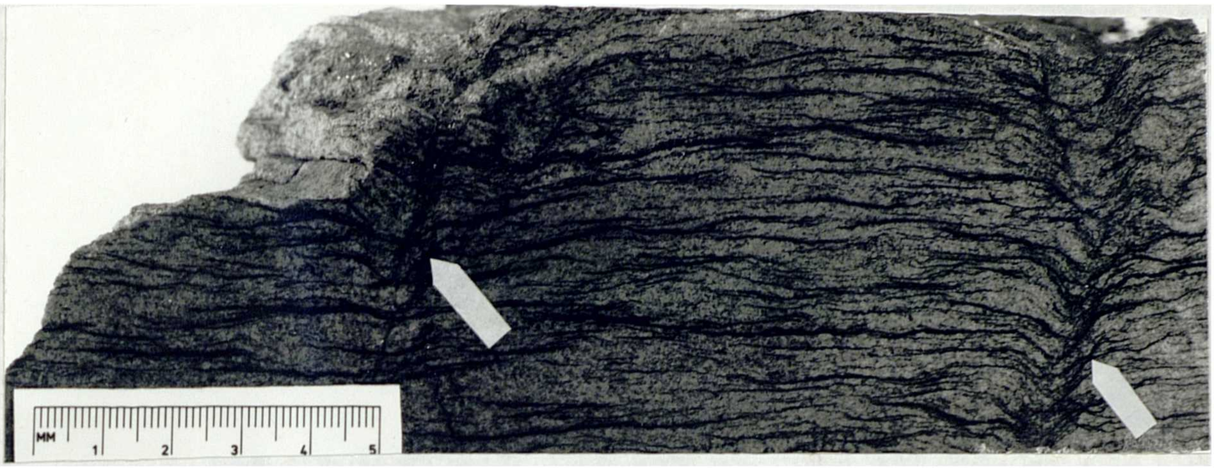

MM 1 2 3 4 5

Plate 126A

Endichnia of Olivellites (arrowed) and Pelecypodichnus (abundant elliptical traces) in Lithofacies 19 Turbidite-like Sandstone (Turbidites) exposed in Scotland Flags Mudstone (Prodelta) of Rake Dike (SE 100052, 10-15m level, 'c' sequence, Fig. 12). Note cross over of Olivellites over its previous path (SE part of Plate). Olivellites in Plate is a positive feature.

Plate 126B

Endichnia of Olivellites and Pelecypodichnus in Rake Dike (negative feature). (Plate 126B is the counterpart of Plate 126A).


0
cm
5

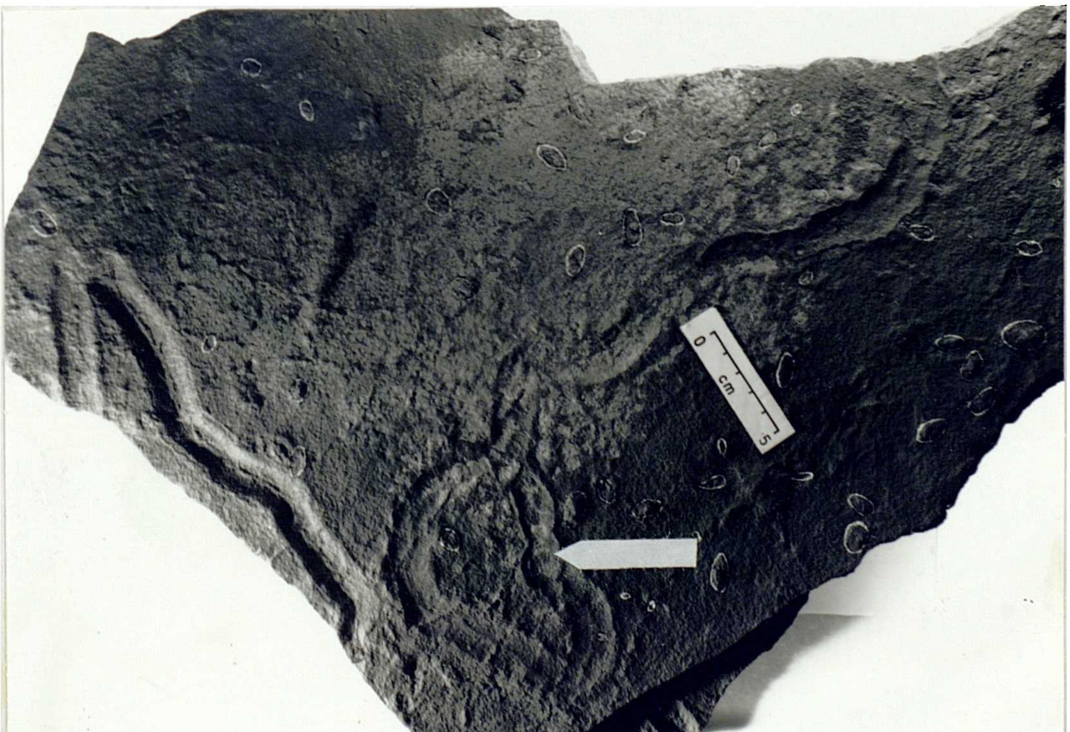

0
cm
5

Plate 127

Cubichnia (resting trace) of Pelecypodichnus (commonly 3cm long) in the sole of a lithofacies 10, Trough Cross Bedded Sandstone (Levee) of the Pule Hill Grit sequence in Harper Clough Quarry (SD 717318, level 12m, Fig 78B) Plate 127 is in the same quarry and level as in Plate 111 but taken from a different position to illustrate the abundance of the trace fossils and the gradational base of the Sandstone unit on which it occurs. One penny piece is 20mm in diameter.

Plate 128

Pelecypodichnus bump with rough surface due to truncation in the sole of a lithofacies 8, Trough Cross Laminated Sandstone (Distributary Channel or Mouth Bar) in the Pule Hill Grit sequence of Branshaw Quarry (SE 031402, level 17m a sequence Fig. 15). One penny piece is 20mm in diameter.

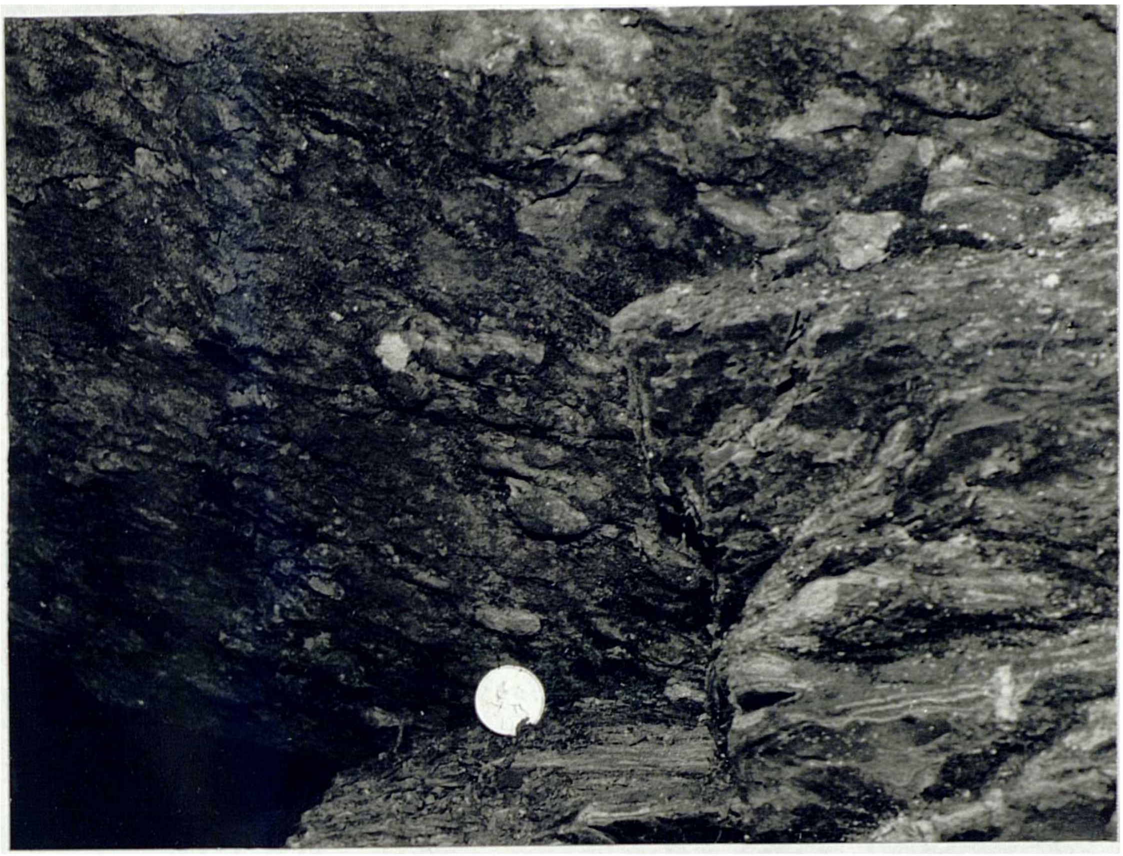


Plate 129

Unoriented Cubichnia (resting traces) of Pelecypodichnus in the sole of a lithofacies 14, Horizontal Bedded Sandstone (Mouth Bar) in Pule Hill Grit sequence at Ramsden Clough (SE 121038, 64m level 'd' sequence, Fig. 12). Note the high population density. Ten pence piece is 29mm in diameter.

Plate 130

Highly organised Pelecypodichnus, arranged to form patterns of polygons, in a lithofacies 10, Trough Cross Bedded Sandstone (Crevasse Channel) in the Scotland Flags sequence at Foster Clough Quarry (SE 021273, level 10m, Fig. 77).

0 2cm

Plate 131

Dominchnia (dwelling structures) of <u>Pelecypodichnus</u> (endichnial tube, length 35cm) in a lithofacies 8, Trough Cross Laminated Sandstone (Distributary Channel or Mouth Bar) of the Pule Hill Grit sequence at Branshaw Quarry (SE 031402, 18m level, 'a' sequence Fig. 15). 10 on plate means 10cm. Arrows are made along some of the tubes.

Plate 132

Domichnia (dwelling structures) of <u>Pelecypodichnus</u> in a lithofacies 8, Trough Cross Laminated Sandstone (Mouth Bar area) in the Scotland Flags Quarry. (SE 033268, 7-8m level, Fig. 55). Note the highly inclined axes of 20-45^{o} from the vertical of the dwelling structures. (Fifty pence piece is 30mm in diameter).

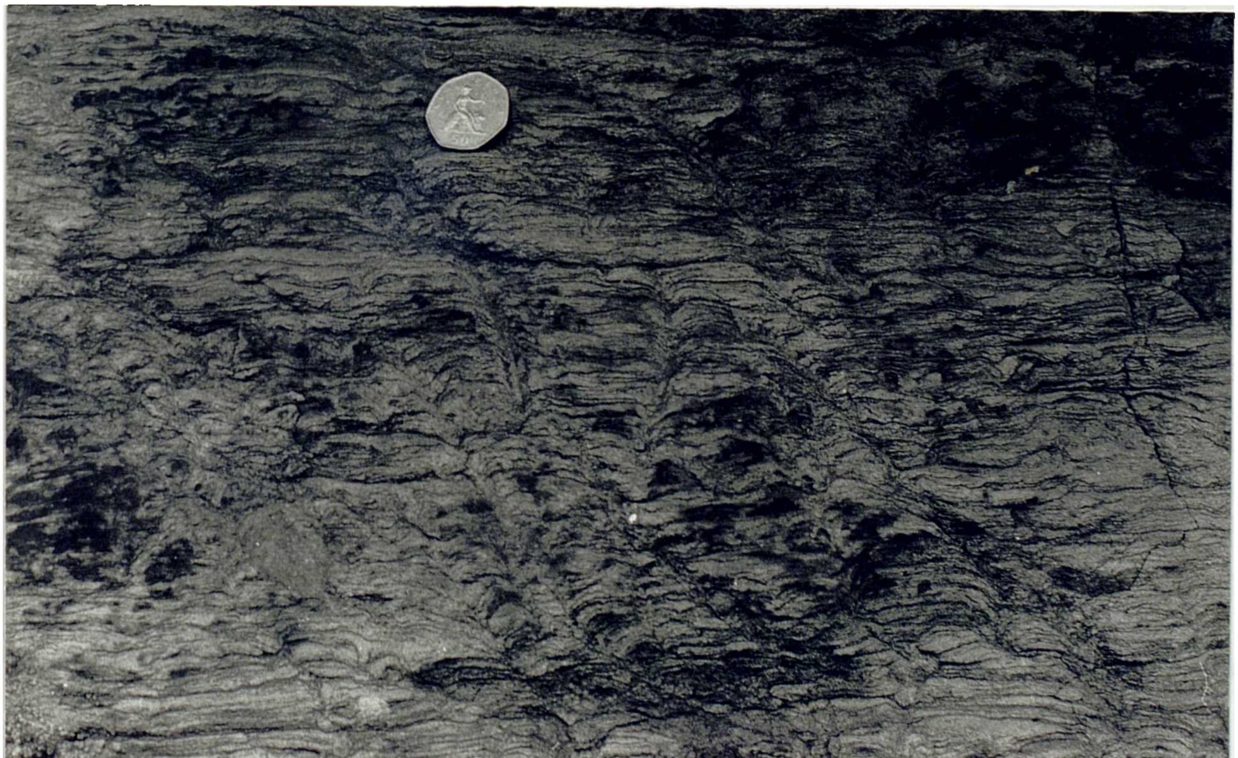


Plate 133

Domichnia (dwelling structures) of Pelecypodichnus in Lithofacies 8, Trough Cross Laminated Sandstone (Levee) in Scotland Flags sequence at Castle Carr Quarry (SE 028301). Length of the dwelling structure 40cm. (Hammer 33cm for scale; chalk marks trace of tube which starts at level of handle end to the top of sandstone unit. Top and basal parts of shaft indistinct in picture).

Plate 134

Fodinichnia (feeding structure) of Phycodes curvipalmatum in the sole of a lithofacies 13, Scour based Sand body (Distributary Channel) in the downthrown Hazel Greave Grit at Wicking Crag Quarry (SE 052372, see Plate 110 for the position of this sand body). Note the cross cutting of the tubes. See Fig. 99 which is a traced sketch of this plate for the explanation of the lettered notations.

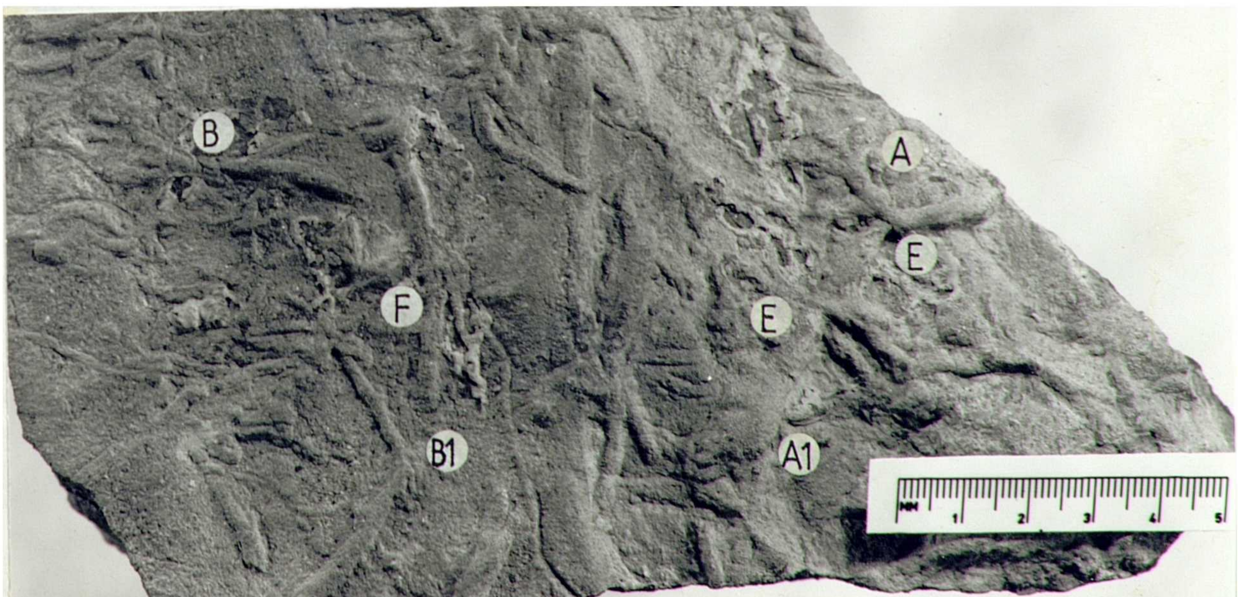

B
A
E
F
E
B1
A1
1
2
3
4
5

Plate 135

Same as in Plate 134 except for the more complex structure and the presence of a structure resembling cf. Nereites (arrowed). (See Figure 100, the traced sketch of this plate illustrating the complex feeding structures).

Plate 136

Planolites in the sole of a lithofacies 10, Trough Cross Bedded Sandstone (subaqueous levee in the mouth-bar area) of the Pule Hill Grit sequence in Park Wood Quarry 3 (SE 067406, level 64-70m,Fig. 15). Two pence piece is 27mm in diameter.

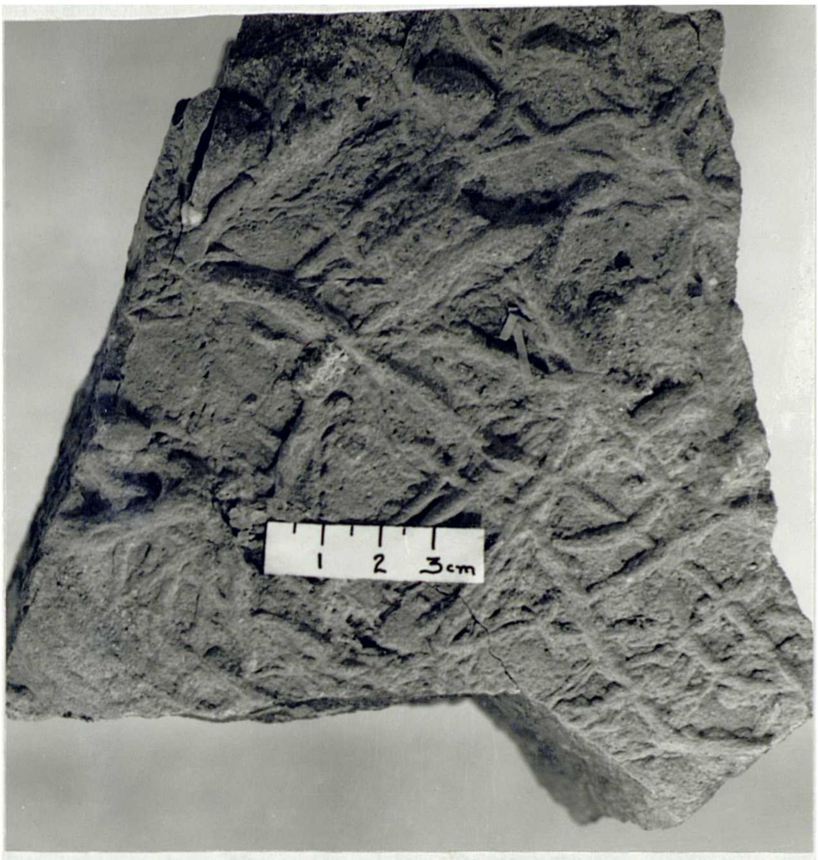
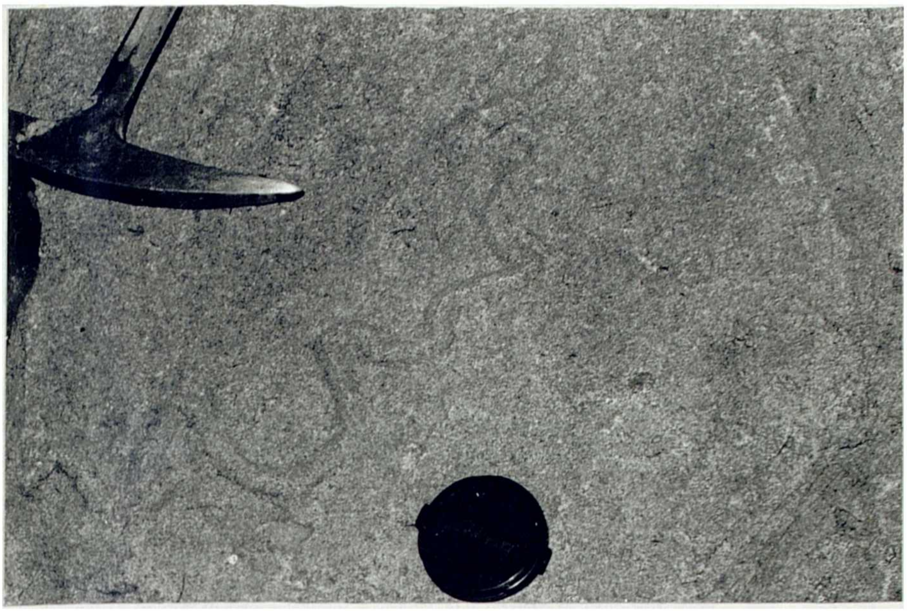

1 2 3cm

Plate 137

Olivellites on the bedding plane of a lithofacies 14, Horizontal Bedded Sandstone (Mouth Bar) of the Pule Hill Grit sequence in Readyshore Scout (SD 942198). Note the Solitary and mildly sinous character of this trail. Nicon cap is 5.5cm in diameter.

Plate 138A

Olivellites in lithofacies 14, Horizontal Bedded Sandstone (Mouth Bar) in the Pule Hill Grit sequence at Ponden Clough. Note the high population density and the marked undulation of the traces (A, B, E = Ridge-like; C, D = Groove-like). Length of compass 10cm (SD 980364, 30m level, Fig. 17).



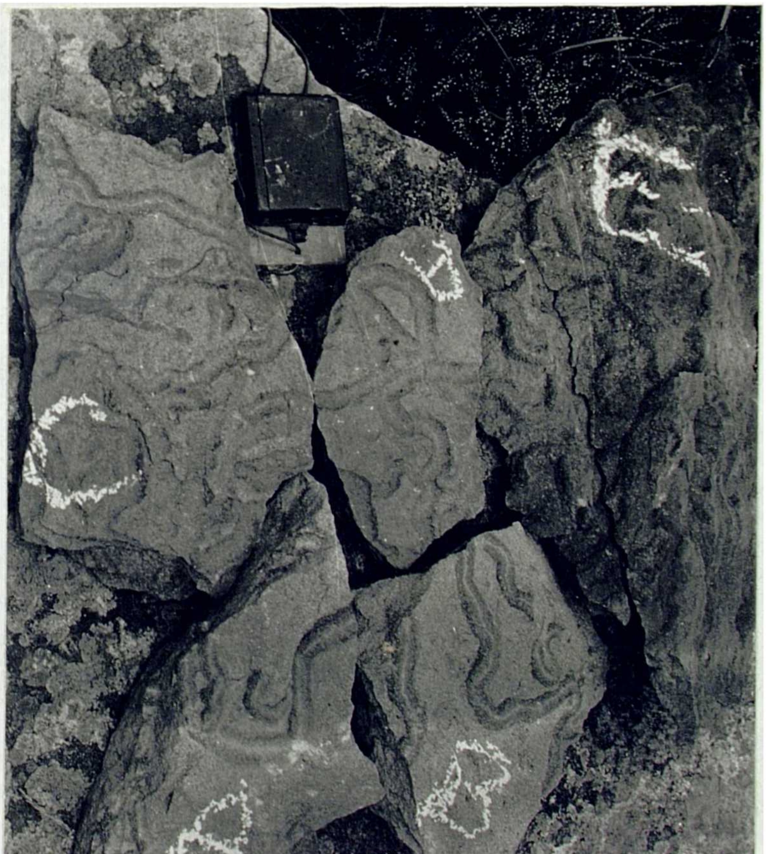

E
D
C
A
B

Plate 138B

Repichnia of Olivellites in Ponden Clough. Plate is from the same Clough section and level as in Plate 138A but shows the sharp turns of up to 90^{0} (arrowed) and doubling back, sometimes cross-cutting its previous path (see position A).

Plate 139

A polished vertical section perpendicular to the bedding plane plus some top plane portraying the vertical relationship of paths of Olivellites in Ponden Clough. (Sample collected from the same section and level as in Fig. 138B).


A
5cm

Plate 140

Plate is from the same section and level as in Plate 139 but shows larger extents of the affected rock section. (Picture taken in the field. Two pence piece is 27mm in diameter).

Plate 141

Repichnia (crawling traces) of Olivellites in lithofacies 14, Horizontal Bedded Sandstone (Mouth Bar) in the Pule Hill Grit sequence of Bare Clough (SE 019309, level 42m, Fig. 14). Note the remarkable cross-cutting of traces. Nicon cap is 5.5cm in diameter.

Plate 142A

Repichnia (crawling traces) of Olivellites in lithofacies 14, Horizontal Bedded Sandstone (Minor Mouth Bar) in the Upper Kinderscout Grit in Rag Clough (SE 014338, 25m level, Fig. 20). Note groove-like counterpart of medial curve. Note also that Plate 142A is a negative structure.

Plate 142B

Repichnia of Olivellites in Rag Clough. (Note ridge-like medial cord). Plate 142B is from the same section and level as in Plate 142A but is a positive feature.


A
0 cm 5

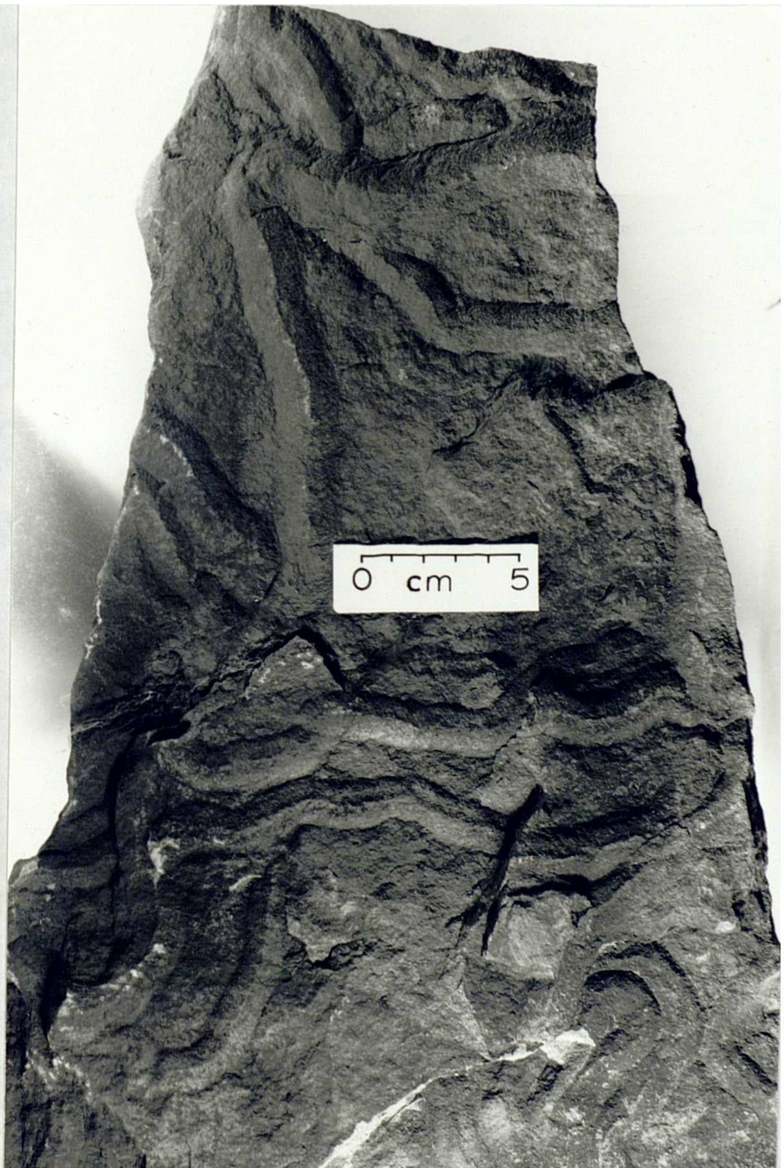

0 cm 5

Plate 143A

<u>'Solicia'</u> on top of a lithofacies 10, Trough Cross Bedded Sandstone (subaqueous levee in a mouth-bar area) in the Pule Hill Grit sequence at Park Wood Quarry 3 showing meandering epichnial ridges (SE 067406, 65m level, Fig. 15). Nicon cap is 5.5cm in diameter.

Plate 143B

<u>Scolicia</u> in Park Wood Quarry 3, showing meandering epichnial ridges. (Plate 143B occurs in the section as in Plate 143A but from level 67m, Fig. 15).

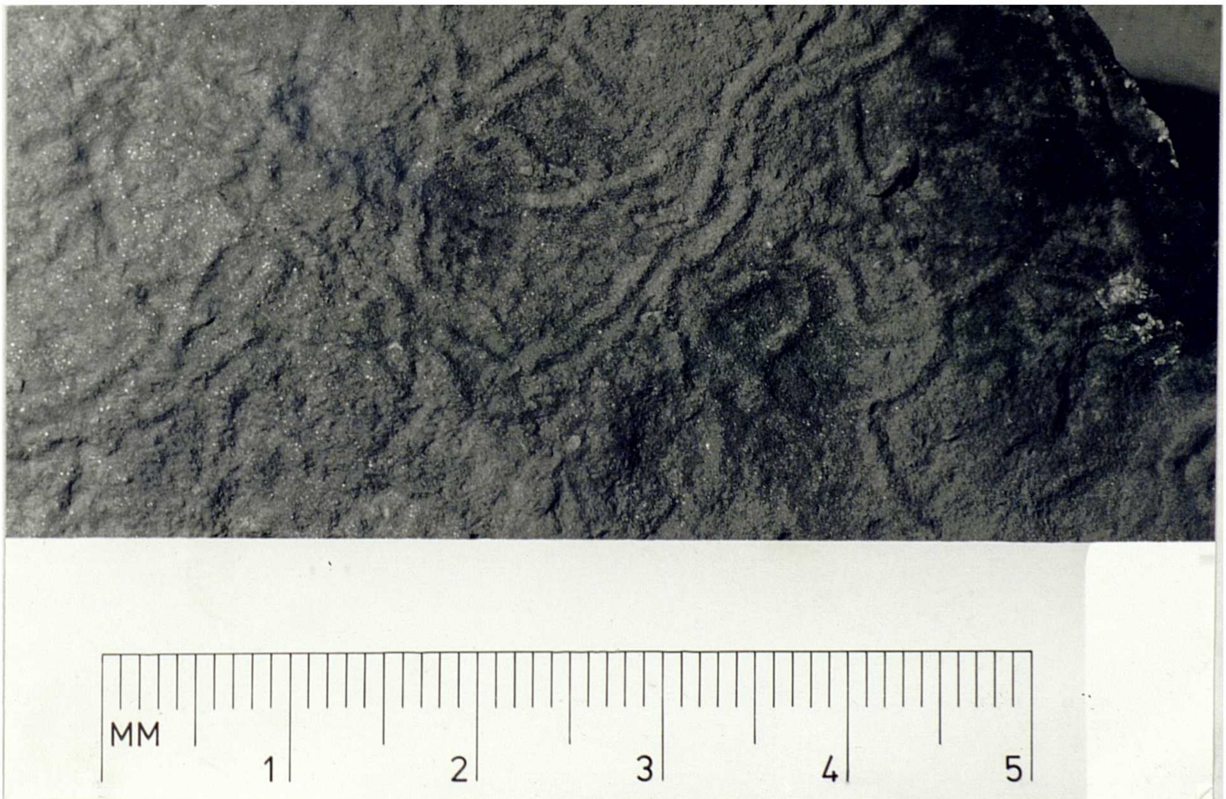

MM
1
2
3
4
5

Plate 144A

Zoophycos (Negative endichnial feature), in lithofacies 3, 'Bluestone',a bluish-grey micaceous silty mudstone (Marine Prodelta), occurring in Pule Hill Mudstone at Ponden Clough. (SD 981365, 2m level, Fig. 17).

Plate 144B

Zoophycos (Positive endichnial feature), in the same section and level as in Plate 144A, its counterpart. Arrow points at marginal tunnel.


MM
1
2
3
4
5

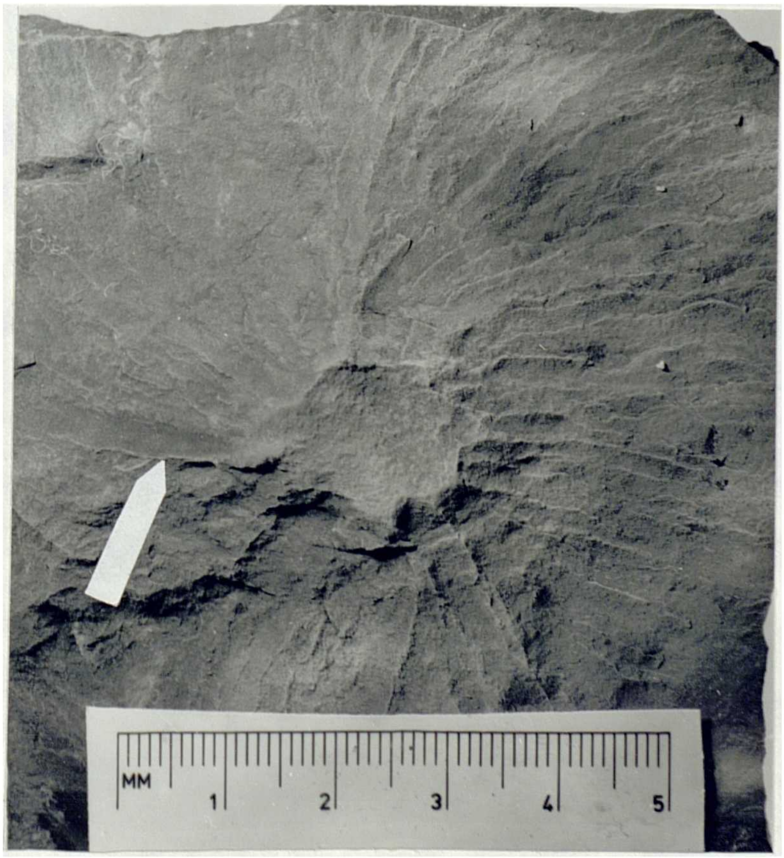

MM
1
2
3
4
5

Plate 145

Loop trails (Epichnial ridges) on top lithofacies 10, Trough Cross Bedded Sandstone (Channel 2) in Pule Hill Grit Sequence in Fletcher Bank Quarry (SD 805165, 13m level, Southern Vertical Section, Fig. 59).


MM
1
2
3
4
5

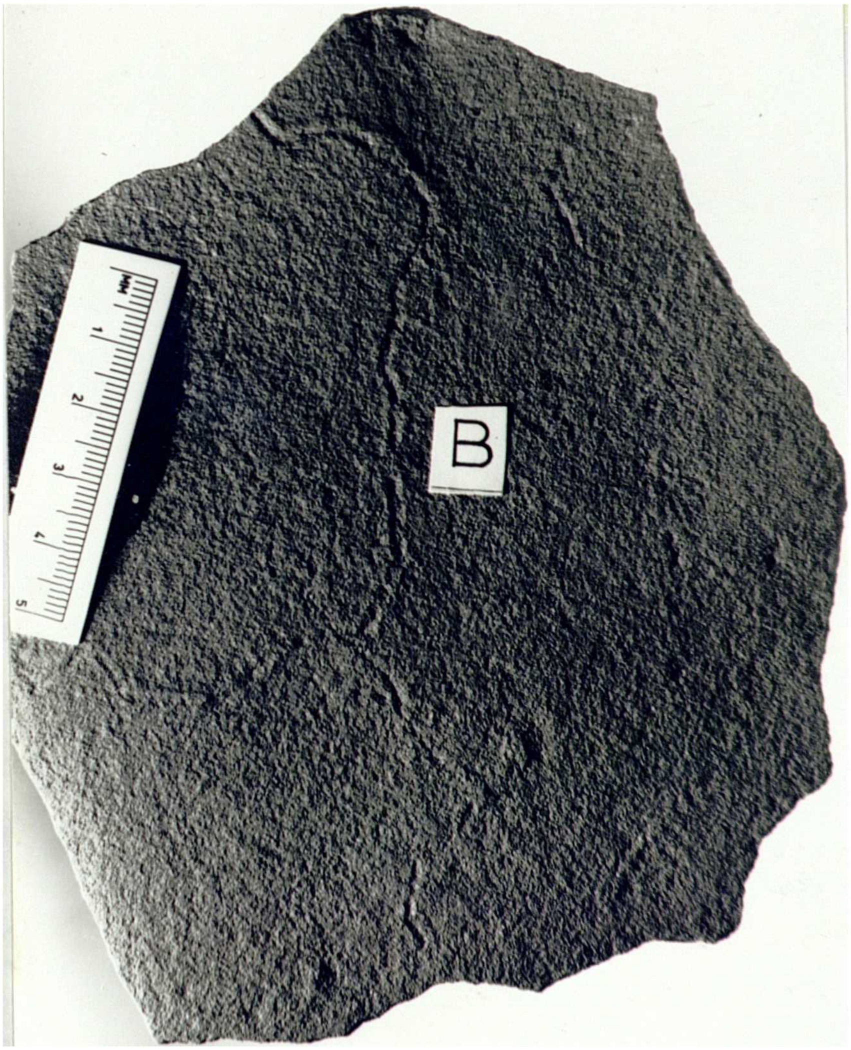
Plate 146A

Sinuous trails (Endichnial ridge) in lithofacies 6, Siltstone (Mouth Bar) in Pule Hill Grit sequence at Light Hazzles Clough (SD 956193).

Plate 146B

Sinuous trails (Endichnial groove), Light Hazzles Clough. (Plate 146B is the counterpart of Plate 146A).


A
MM 1 2 3 4 5


B
MM 1 2 3 4 5